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ESTIMATION OF EVAPORATION FROM FARM PONDS[1]

R.H. Shaw and A. Yi-Ming Yao[2]

More and more farm ponds are being built in Iowa. These ponds may furnish water for irrigation and livestock, or provide recreational areas. Water may be lost from these ponds by evaporation or seepage. Seepage losses will depend upon the material used as a base for the pond and upon the construction of the pond. Evaporation losses will be related to the pond area and to certain meteorological factors. An estimate of the losses and uses for stored water needs to be made to help determine the size of the pond.

The relation between evaporation pan and lake evaporation has been studied by meteorologists. Many have considered pan evaporation of little value for estimating lake evaporation. Sutton (4), Cummings (1), and Kohler, Nordenson, and Fox (2) found appreciable errors can be involved in relating lake evaporation to class A Weather Bureau standard evaporation pans because of advected energy into the areas and heat transfer through the pan. However, in the case of small farm ponds, both water surfaces (pan and pond) represent relatively small water surfaces, very often surrounded by a relatively dry area. This study was designed to measure the relationship between a small pond and evaporation pan losses.

NATURE AND SOURCE OF DATA

The pond used in this study is located at the Albia Pasture Farm in south central Iowa, and at the time of observation covered approximately one-half acre. A continuous record of the water level in the pond was made using a Bendix Friez FW-1 water stage recorder in a water level well. The class A Weather Bureau standard evaporation pan was located about one-quarter mile from the pond at the weather station. Data were computed for periods from 7 p.m. to 7 p.m.

Class A Weather Bureau standard evaporation pan data were used from weather stations at Ames, Norwich (Clarinda), Iowa City, and Cherokee. Data have been recorded at these locations starting in 1933 at Ames and 1938 at the other stations. The record at Cherokee terminated in 1953.

[1]Journal Paper No. J-3233 of the Iowa Agricultural and Home Economics Experiment Station, Ames, Iowa. Projects 1297 and 1247. This work partially supported by U.S. Weather Bureau Contract 8808.

[2]Professor, Agricultural Climatology, Agronomy Department, and formerly United Nations Scholar; now on staff Taiwan Weather Bureau, Taipei, Formosa.

RESULTS AND DISCUSSION

Evaporation pan values are of different magnitude than pond evaporation, but they can be related. Pan evaporation is greater than pond evaporation because of transfer of heat from the surrounding area into the small pan. Incident radiation on the shallow pan may also result in a different water temperature than for the deeper pond.

The data on pan and pond water loss for the individual days are plotted in Fig. 1 for 1955 and Fig. 2 for 1956. The linear regression lines computed for the two years were:

1955 $\hat{Y}_{pond} = 0.05 + 0.65X, \; r = 0.94^{**}$[1]

1956 $\hat{Y}_{pond} = 0.08 + 0.61X, \; r = 0.85^{**}$

When the data for the two years are combined, the relation becomes:

$$\hat{Y}_{pond} = 0.07 + 0.62X$$

According to Smith (3), this gives an estimate of the daily rate of seepage from the pond as 0.07 inches. Since this pond is used for watering livestock, this water use is also included in this figure. Pond evaporation was 0.62 that of pan evaporation.

Evaporation pan data which are available for a longer period provide a means of estimating pond evaporation. In using these data, the same relationship between pan and pond must be assumed as was determined for the two years at Albia. Using pan data for Ames, pond evaporation has been estimated for each month. (Table 1)

Table 1. Estimated pond evaporation per month. (Based on Ames 1933-1956)

Month	Pond evaporation (inches)			State precipitation (inches)
	Average	High	Low	Average
April	2.9	4.2	1.6	2.6
May	4.0	7.5	2.7	4.0
June	4.6	7.6	2.8	4.5
July	5.4	8.6	4.2	3.6
August	4.6	6.7	3.2	3.8
September	3.5	5.7	2.7	4.0
October	2.2	3.4	1.5	2.3

July has had the highest estimated evaporation with an average of 5.4 inches and a maximum of 8.6 inches. July and August would normally have evaporation greater than precipitation.

[1]Significant at 99 per cent level.

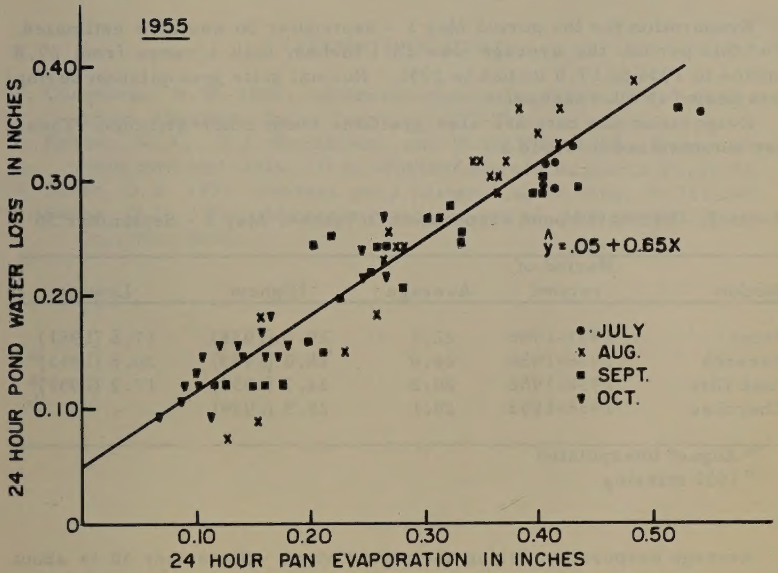

Fig. 1. Comparison of daily pan evaporation and pond water loss, 1955.

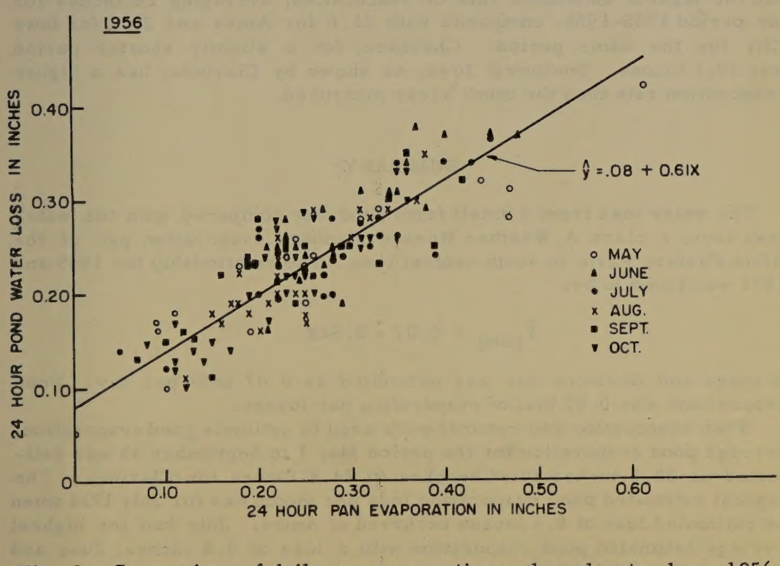

Fig. 2. Comparison of daily pan evaporation and pond water loss, 1956.

Evaporation for the period May 1 - September 30 was also estimated. For this period, the average was 22.1 inches, with a range from 29.8 inches in 1934 to 17.6 inches in 1951. Normal state precipitation during this period is 19.9 inches.

Evaporation pan data are also available from other stations. These are summarized in Table 2.

Table 2. Estimated pond evaporation in inches, May 1 - September 30

Station	Period of record	Average	Highest	Lowest
Ames	1933-1956	22.1	29.8 (1934)	17.6 (1951)
Norwich	1938-1956	24.0	28.0 (1939)	20.6 (1951)[a]
Iowa City	1938-1956	20.2	24.7 (1955)	17.2 (1951)[a]
Cherokee	1938-1953	20.1	25.5 (1939)	- - - [b]

[a] August interpolated
[b] 1951 missing

Average evaporation during the period May 1 - September 30 is about the same as normal precipitation. However, during periods of below normal rainfall, when evaporation losses could be expected to be above average, evaporation is greater than rainfall. Norwich (Clarinda) has had the highest estimated rate of evaporation, averaging 24 inches for the period 1938-1956, compared with 21.6 for Ames and 20.2 for Iowa City for the same period. Cherokee, for a slightly shorter period was 20.1 inches. Southwest Iowa, as shown by Clarinda, has a higher evaporation rate than the other areas measured.

SUMMARY

The water loss from a small farm pond was compared with the water loss from a class A Weather Bureau standard evaporation pan at the Albia Pasture Farm in south central Iowa. The relationship for 1955 and 1956 was found to be:

$$\hat{Y}_{pond} = 0.07 + 0.62X$$

Seepage and livestock use was estimated as 0.07 inch per day. Pond evaporation was 0.62 that of evaporation pan losses.

When evaporation pan records were used to estimate pond evaporation, average pond evaporation for the period May 1 to September 30 was estimated as 20.1 inches for Cherokee to 24.4 inches for Clarinda. The highest estimated pond evaporation loss per month was for July 1934 when an estimated loss of 8.6 inches occurred at Ames. July had the highest average estimated pond evaporation with a loss of 5.4 inches; June and August averaged 4.6 inches.

LITERATURE CITED

1. Cummings, N.W. 1950. Minimum evaporation from a water surface. Amer. Geophys. Union Trans. 31:757-762.
2. Kohler, M.A., T.J. Nordenson, and W.E. Fox, 1955. Evaporation from pans and lakes. U.S. Weather Bureau Research Paper 38.
3. Smith, D.D. 1955. Storage pond design. Agric. Eng. 36:743-746.
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LEGUMINOSAE OF THE NORTH-CENTRAL UNITED STATES III. MIMOSOIDEAE AND CAESALPINIOIDEAE[1]

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The area covered and method of treatment employed, in this series, are described in earlier publications (Isely, 1951, 1955a).

The identification of the species of Mimosoideae and Caesalpinioideae of the north-central states by seed characters is treated in another publication (Isely, 1955b); the seeds of these subfamilies and the Papilionoideae are discussed on a comparative basis (Isely, 1955c).

Subfamilies of the Leguminosae

The fundamental character of the Leguminosae is the gynaecium which consists of a single carpel bearing ovules marginally along the ventral suture.[3] The fruit, a legume or pod, often dehisces by splitting along both sutures; however, indehiscence is secondarily derived in several elements of the family. Within the above circumscription, the Leguminosae may be divided into three subfamilies, the Mimosoideae, Caesalpinioideae and Papilionoideae. These are treated as separate families by some authors. Jones (1955) has recently elevated the group to ordinal rank.

Most of the familiar cultivated and native legumes of the north-central states are members of the Papilionoideae. The Mimosoideae and Caesalpinioideae are primarily tropical groups, and are scantily represented within our range.

[1]Journal Paper No. J-3212 of the Iowa Agricultural and Home Economics Experiment Station. Project 1073.

[2]Figures by Barbara Martin Stewart.

[3]Some authors, e.g. Woodson and Schery (1950, p.184), state that the ovules are borne from the dorsal suture. Possibly this inconsistency arises from ambiguities in application of the terms ventral and dorsal. "Ventral," as herein employed, has reference to the margin of a conduplicate carpel which contains the contiguous lateral traces (presumably the adjoining edges of the folded sporophyll); dorsal suture refers to the edge bearing the midvein. A fuller exposition of the use of the terms ventral and dorsal as applied to such carpels is presented by Bailey and Swamy (1951).

With respect to orientation in the flowers, the ventral suture of the carpel is on the same radius with (opposite) and contiguous to the upper petal–the standard in those flower types possessing bilateral symmetry. The dorsal suture is alternate with and contiguous to the two lower petals.

Synopsis of Subfamilies

1. Corolla irregular (papilionaceous), the petals imbricate with the upper (standard) external in bud; stamens ten or fewer, monadelphous, diadelphous or (less frequently) free; embryo curved; leaves not twice-pinnate. Papilionoideae

1. Corolla regular or slightly irregular; petals valvate or imbricate with the upper enclosed in bud; stamens usually 10 — many, not diadelphous; embryo straight; leaves often twice-pinnate.

   2. Flowers in dense heads or spikes; stamens much exserted, conspicuous; perianth valvate, small. Mimosoideae

   2. Flowers variously arranged, not in heads; stamens scarcely exserted; corolla imbricate in bud, conspicuous. Caesalpinioideae

MIMOSOIDEAE

Herbs or trees. Leaves twice-pinnate, often sensitive. Flowers usually small, clustered in heads, umbels or spikes. Perianth inconspicuous. Corolla regular, valvate in bud, the petals separate or partially fused. Stamens (5) 10-many, long exserted. Legumes variable. Seeds with a horseshoe-shaped line on each face. Embryo straight, usually surrounded by copious endosperm.

In this subfamily, the stamens are the conspicuous part of the flower. Usually 10-many per flower, their slender filaments greatly exceed the perianth, and are usually responsible for the characteristic shape and color of the flowering heads or spikes.

The complex and often large leaves, bearing up to fifteen pairs of primary divisions (pinnae), each with 15-30 pairs of leaflets may thus possess several hundred ultimate divisions. Both the primary and secondary divisions appear fundamentally even-pinnate, but this is sometimes obscured by irregular positioning. The leaflets are entire, usually quite small with reduced or nonevident venation. Frequently they are strongly asymmetric, particularly at the base, and may be attached at one corner.

The Mimosoideae are primarily a tropical group. Most of the large genera are represented in both hemispheres. Of the six species treated below, only two are widely distributed in the north-central states.

The generic distinctions in the following key have reference only to the species included in our flora.

Key to Genera

1. Plant a spiny tree or shrub with greenish-white flowers in spikes and fruits 2–4 dm long, occurring in our range only locally in south-central Kansas. . . . . Prosopis

1. Plants not as above.

   2. Plants woody; stamens numerous.

      3. Flowers pale yellow to orange-yellow; plant a native shrub. . . . . Acacia

      3. Flowers pink; plant an introduced tree, usually seen in cultivation. . . . . Albizzia

   2. Plants herbs; stamens 5–12.

         4. Stems prickly; flowers reddish. . . . . Schrankia

         4. Stems not prickly; flowers whitish. . . . . . Desmanthus

ACACIA Mill.

Shrubs or trees. Flowers capitate or in short racemes. Sepals and petals 4–5. Stamens many. Pods diverse. Seeds often with a conspicuous funiculus.

Acacia is one of the largest of the genera of legumes and contains several hundreds of species indigenous primarily in Africa, Australia, and the American tropics. Some authors subdivide it into a number of segregate genera, e.g., Britton and Rose (1928).

Chromosome numbers of 2n = 26, and 2n = 52 have been reported in Acacia (Atchison, 1948; Darlington and Wylie, 1955). Ten American species studied by Atchison (l.c.) all possessed 2n = 26. A. angustissima, herein treated, was not investigated.

The genus Acacia has been attributed to several authors. Author citation has recently been discussed by Isely (1957).

Literature

Britton and Rose (1928, 84-120). American species (as Acacieae, including 12 genera).
Fernald (1950, 883-884). Northeastern U.S.
Gleason (1952, 379). Central and eastern U.S.
Isely (1957). Author citation for genus.
Wiggins (1942). Acacia angustissima.

Acacia angustissima (Mill.) Ktze. [Incl. Acaciella hirta (Nutt. ex T. and G.) Britt. and Rose]. Plate I.

A low or sprawling shrub. Stem and leaf rachises usually with stiff, whitish pubescence. Stipules lanceolate, early deciduous. Pinnae (8) 10-14 pairs, each bearing 20-35 pairs of rigid leaflets. Flowers in axillary or racemed heads which are 1-1.5 cm across, yellow-white to orange. Pod membranous, reddish-brown to black, oblong, flat, 4-8 cm long, ca. 1 cm wide. Seeds broadly oval, 3.5 mm long, brown.

Distribution and habitat—Acacia angustissima is widely distributed in central America, Mexico, and the southern United States. From east-central Arizona and southern New Mexico it extends northeast to southwestern Missouri and adjacent Kansas. It has been reported along the Gulf coast east to Florida. In the north-central states (Kansas and Missouri), A. angustissima is usually encountered sporadically in uplands, especially limestone hills or bluffs; however, in the southwest it is typical of prairie or desert regions.

Phenology—Flowering May to June.

Variability—Acacia angustissima is a complex of geographical varieties several of which have been accorded specific rank. The north-central states representatives are subherbaceous, sprawling shrubs which may be categorized as variety hirta, (Nutt. ex T. and G.) Robinson [Acaciella hirta (Nutt. ex T. and G.) Britt. and Rose]. The taxonomic description above is limited to this variety. Typical A. angustissima, a taller shrub or small tree with more numerous leaflets and pinnae, occurs in Central America north to Texas. Several additional varieties, indigenous to the southwestern states and Mexico have been characterized by Wiggins (1942).

Discussion—Graham (1941) notes that in Mexico the bark of this plant is employed to induce fermentation in the preparation of alcoholic drinks.

ALBIZZIA Durazz.

Trees. Leaves bipinnate. Flowers in globular clusters. Stamens numerous, joined below. Pods flattened, oblong.

Albizzia is a tropical to subtemperate genus primarily of the Old World, but with a few species in tropical America. It appears to be most closely allied to Pithecellobium and Enterolobium. Most species investigated cytologically have proved to have a 2n chromosome number of 26; the multiples 52 and 104 have each been reported for one species (Darlington and Wylie, 1955).

Literature

Britton and Rose (1928, 43-48). American species.
Fernald (1950, 884). Northeastern U.S.
Gleason (1952, 379). Central and eastern U.S.

Albizzia julibrissin Durazz. Silk-tree, Mimosa. Plate I.
A small tree. Leaves large with numerous pinnae and leaflets. Leaflets strongly asymmetric, curving slightly forward, mucronate. Flower clusters racemed, 10–15 flowered, pinkish. Corolla funnel-form, lobed at apex. Filaments 2–3 cm long; anthers small. Pods 1–2 dm long, oblong, flattened, membranous, tapering to a beak. Seeds elliptic-oblong, ca. 8 mm long, light brown.

Chromosome number–Somatic 26 (Berger and Witkus, 1950); somatic 52 (Yamazaki, 1936).

Distribution and habitat–A native of eastern Asia, the silk tree is extensively grown as an ornamental in southern states and naturalized to some extent about towns and along roadsides. It is sporadically cultivated and escaped further north, occurring in our area only in southern Missouri and Kansas.

DESMANTHUS Willd. (Acuan Medic.)

Perennial herbs with bipinnate leaves. Stipules filiform, usually persistent. Leaf rachis with a reddish, sessile gland between lowest pair of pinnae, sometimes further glands above. Flowers in axillary, whitish-green heads. Petals essentially separate. Stamens 5–10 (our species 5). Pods ovate to oblong.

Desmanthus (ca. 30 species) is located primarily in the American tropics. Some ten species occur in the southwestern United States of which two reach our area. Woodson and Schery (1950) indicate that Desmanthus is "obviously close to Leucaena." On the other hand, Turner and Beaman (1953) suggest that its relationships are more properly with Dichrostachys and other members of the Adenanthereae rather than with the Eumimoseae where it is conventionally placed.

Chromosome complements, 2n = 28 were found in 5 species studied (Turner and Beaman, 1953).

The name, Desmanthus Willd. (1806) is conserved over the earlier Acuan Medic. (1786).

Literature

Britton and Rose (1928, 131-138). American species (as Acuan).
Fernald (1950, 884). Northeastern U.S.
Gleason (1952, 380). Central and eastern U.S.
Turner (1950). Texas.
Turner and Beaman (1953). Chromosome complements.

Key to species

1. Pods curved, broad, crowded together in dense heads; flowering peduncles 2 cm or more, petioles 1 cm or more in length. . . . . Desmanthus illinoensis

1. Pods straight, narrowly oblong, relatively few in each head; flowering peduncles usually less than 2 cm, petioles 5–8 mm long. . . . . D. leptolobus

Desmanthus illinoensis (Michx.) MacMill. Plate II.
Plants from a deep, woody tap root. Stems clustered, ascending, with a shrub-like appearance, usually glabrous. Stipules 5–8 mm long, usually persistent. Leaves 8–15 cm long. Leaflets 2–3 mm in length, glabrate or very finely hairy; midvein offset. Peduncles arising in axils of upper leaves, 2–6 cm in length. Pods numerous in head-like clusters, falcate to lunate, 1.5–2.5 cm long, flattened, often somewhat twisted. Seeds obovate, usually somewhat asymmetric, ca. 4 mm long, brown.

Distribution and habitat–Plains states and adjoining provinces immediately to the east. Local in northern and eastern part of range, (possibly of recent introduction), more common south and west. Open areas, roadside ditches, railroad right-of-ways, prairies, usually alluvial or moist sandy soil.

Phenology–Flowering July to August.

Variability–The pods are usually falcately curved and are so characterized in descriptions. However, the degree of curvature is subject to considerable variation. I have seen colonies in which the pods were nearly straight, thus more closely resembling other species of Desmanthus.

Discussion–Roots examined in the field appear to be nodule-bearing. Graham (1941) believes this species to be of value in erosion control.

Desmanthus leptolobus T. and G. Plate II.
Vegetatively similar to preceding species but lower. Leaves smaller, on petioles less than 1 cm in length. Peduncles usually not exceeding 2 cm. Pods about 5 in a cluster, narrowly oblong (3–6 cm), slightly constricted between seeds, about as thick as wide. Seeds oblong, about 4.5 mm long and 2 mm wide, shiny brown.

Distribution and habitat–Southern Missouri and Kansas, south to Texas. Prairie areas.

PROSOPIS L. (Incl. Algaroba (DC.) Benth.)

Spiny shrubs or trees. Leaves bipinnate with numerour leaflets. Flowers in axillary spike-like racemes, greenish-yellow. Stamens 10, separate. Pods indehiscent, straight or coiled.

Prosopis is genus of 30–40 species. It is distributed from the southwestern United States, south by way of the South American cordillera to Argentina and Chile. It also occurs in Asia and Africa.

Britton and Rose (1928) break Prosopis into 3 genera: Sopropis (gamopetalous corolla, one species), Strombocarpa (coiled pods, 2 species), and Neltuma (straight pods, remaining species).

The majority of species of Prosopis investigated cytologically possess a somatic chromosome number of 28; 56 is reported for two species and 112 for one (Darlington and Wylie, 1955). This suggests that a base number of 14 is the usual rule in this genus. However, the numbers 26 and 52 are also reported for one species.

Literature

Benson (1941). Monograph, U.S. species.
Bogusch (1950). Bibliography and literature review.
Britton and Rose (1928, 182-187). American species (as Sopropis, Strombocarpa, Neltuma).
Burkart (1940). Monograph.
Burkart (1943, 126-142). Species and economic uses.
Graham (1941, 91-93). Food for wild life.

Prosopis juliflora (Swartz) DC. [Prosopis chilensis (Mol.) Stuntz in part; P. glandulosa Torr.; P. velutina Woot.]. Mesquite, Algaroba. Plate III.

Deep-rooted shrub or small tree. Twigs spiny. Leaves mostly on short spurs, with 2 main pinnae, each with 7-15 pairs of leaflets, glabrate or hairy; petiole terminus between pinnae, spine-tipped. Flowers fragrant; stamens about twice as long as corolla. Pods oblong, 2-4 dm long, somewhat constricted between the seeds, short beaked. Seeds individually enclosed within bony endocarp segments of fruit. Seed elliptic, biconvex, 6.5 mm long, brown.

Chromosome number—Somatic 56 (Atchison, 1951); somatic 52 (Sampath and Ramanathan, 1949); somatic 26 (Ramanathan, 1950; as Prosopis glandulosa Torr.). No interpretation of this variance is attempted in view of uncertainty as to identity of materials employed.

Distribution and habitat—Southwestern states, Mexico and West Indies. In the United States, southern California to western Oklahoma and eastern Texas, touching south-central Kansas. Deserts, rangeland, and along rivers, often the dominant element of the vegetation.

Phenology—Flowering primarily spring, but continuing sporadically throughout summer.

Nomenclature—Nomenclatorial inconsistency for this species is primarily a reflection of differences in taxonomic judgment. Some authors have considered the North American mesquites as varieties of the Prosopis chilensis of Argentina and Chile. Contrariwise the names, P. glandulosa and P. velutina, have been employed for elements which are herein considered to fall within the specific limits of P. juliflora.

Variability—There has been little agreement as to the precise delimitation of this species, and the problem is not pertinent to the present study. The most critical treatment is that of Benson (1941) who con-

siders Prosopis julifora as a complex of geographical races extending into Central America, but not including South American forms.

Discussion—Mesquite is included in our treatment by virtue of its occurrence in south-central Kansas. It has been reported from Missouri several times, but has apparently not persisted on more than a local basis. It is wide spread throughout the southwestern states, and is the dominant species over thousands of acres of overgrazed rangeland. Apparently mesquite originally occurred primarily along the water courses. Invasion of the ranges has taken place the last 75–100 years as a consequence of the activities of the white man.

Utilization of this species, past and present, is reviewed by Bogusch (1950; with a very extensive bibliography), Burkart (1943), and Hosaka and Ripperton, (1944; the "most valuable introduced tree" in Hawaii). Its value for wild life is discussed by Graham (1941).

SCHRANKIA Willd. (Leptoglottis DC.; Morongia Britt.)

Perennial herbs or shrubs with sprawling, prickly stems. Leaves sensitive. Flowers in axillary, many-flowered, pink, globose heads. Calyx reduced. Corolla funnelform, lobed at apex. Stamens 10–12. Pods narrowly oblong, somewhat quadrangular, prickly. Seeds irregularly quadrate, tending to be obliquely truncate at apex and pointed at base, about 4.5 mm long.

Schrankia is a small (20 plus species), warm American genus. Both Turner (1950a) and Woodson and Schery (1950) point to the close relationships of Schrankia with Mimosa.

Chromosome number determinations have been made for two species in this genus; somatic 16 and 24 (Atchison, 1949; Turner and Beaman, 1953).

Schrankia Willdenow (1806) is a conserved name. It is antedated by Schrankia Medic. (1792), hence Leptoglottis Decandolle (1825) has been taken up by some earlier American authors as the earliest available name. Morongia Britton (1894) was superfluous when published.

Literature

Britton and Rose (1928, 138-144). American species (as Leptoglottis).
Fernald (1950, 884). Species of northeastern U.S.
Gleason (1952, 380). Species of central and eastern U.S.

Schrankia uncinata Willd. [S. nuttallii (DC.) Standl.]. Sensitive-brier. Plate III.

Stems clustered from a long, woody root. Stems and leaf rachises essentially glabrous but with retrose-curved prickles. Stipules persistent, 3–5 mm long, linear-lanceolate. Pinnae 3–7 pairs; leaflets nearly symmetrical with evident venation, mucronate. Pods 1–8 in a cluster, 4–8 (10) cm long, prickly on angles,

beaked. Seeds irregularly quadrate, tending to be obliquely truncate at apex and pointed at base, about 4.5 mm long.

Distribution and habitat–The Great Plains, South Dakota to Texas, southeast into Missouri and Arkansas. Of rare occurrence in eastern Iowa and adjacent Illinois, perhaps once more common, stations now largely destroyed. Prairies, pastures, clearings in woodlands, and along roadsides.

This species is also reported from the southeastern states in various manuals. At this date I have not studied the plant extensively outside of the north-central states, but southeastern specimens seen have proved to be the related Schrankia microphylla (Dryand) McBride. Further clarification must await a more complete study of the species of Schrankia in the United States.

Phenology–Flowering May–June (southern part of range); July–August (northern).

Nomenclature–Most recent authors have treated this species as Schrankia nuttallii (DC.) Standl. The typification of the older name S. uncinata Willd., and its proper application to the sensitive brier of the north-central states has been treated by Gambill (1953) and Isely (1957).

Discussion–Schrankia pods at maturity split into four longitudinal strips, the broadened margins separating from the valves.

CAESALPINIOIDEAE

Herbs or trees. Leaves pinnately compound or simple (Cercis). Corolla irregular or nearly regular; petals imbricate in bud, the upper (equivalent to standard of Papilionoideae) enclosed by lateral and lower petals. Stamens 10, or fewer, ordinarily separate. Seeds usually with abundant endosperm; embryo straight.

The Caesalpinioideae is primarily a tropical group of some 50-60 genera. It is divided into several, reasonably distinct tribes which, because of the small number of genera involved, are not considered in the key below.

Key to Genera

1. Plants trees.

  2. Leaves compound; flowers not pink.

    3. Leaflets 2–3 cm broad; tubular hypanthium longer than the petals and sepals. . . . . Gymnocladus

    3. Leaflets less than 1 cm broad; hypanthium shorter than sepals and petals. . . . . Gleditsia

  2. Leaves simple; flowers pink. . . . . Cercis

1. Plants herbs.

    4. Leaves bipinnate. . . . . Hoffmanseggia

    4. Leaves once-pinnate.

        5. Flowers clustered towards stem apex, often congested in a "terminal" inflorescence; pods somewhat curved, not readily dehiscent; leaflets usually more than 5 mm wide. Cassia

        5. Flowers in axillary 1-2 flowered clusters; pods straight, dehiscent; leaflets usually less than 5 mm wide. Chamaecrista

CASSIA L.

Perennial or annual herbs. Leaves once pinnate, with a gland near base of petiole (in our species). Stipules usually deciduous. Flowers yellow, nearly regular, in axillary racemes or clustered towards stem tip. Sepals essentially separate, rounded at tip. Stamens ten, various in length, three of them usually sterile. Anthers large, basifixed, dehiscent by pores. Pods oblong to linear, laterally jointed, somewhat curved, often breaking into 1-seeded segments. Seeds with an elliptic or oblong lighter colored area on each face.

Cassia in the broad sense represents an immense assemblage (several hundred species) of subtropical to tropical herbs, shrubs and trees. It is widely variable as to flower and fruit characters; the above description is specific for our representatives only.

Some authors have split the Cassia of classical definition (e.g. Bentham, 1871) into several, smaller genera. This is carried to an extreme by Britton and Rose (1930) who, treating the North American members of the tribe Cassieae (essentially the original Cassia), recognize 28 genera. In the present treatment, Chamaecrista is segregated as a separate genus.

Basic chromosome numbers of 6, 7, and 13 are tabulated by both Darlington and Wylie (1955) and Senn (1938a, 1938b) for various species of Cassia. Darlington and Wylie also include species with gametic numbers in the euploid series 8, 16, and 24 (base number 8) but Senn excludes these from Cassia. The presence of several basic chromosome number series within the genus confirms the belief (based largely on morphological variability) that it is somewhat diverse phyletically.

The seeds of various species of Cassia serve as a source of food for numerous birds (Graham, 1941).

Literature

Britton and Rose (1930, 227-269). North American species (as Cassieae).

Fassett (1939, 22-28). Wisconsin species.
Fernald (1937). C. marilandica and hebecarpa.
Fernald (1950, 885-886). Northeastern U.S. species.
Gleason (1952, 384-386). Central and eastern U.S. species.
Pollard (1894). North American species.

Key to Species

1. Leaflets broadly obovate, rounded at apex, usually 6; pods quadrangular, narrowly linear, not segmented, 10-20 cm long. . . . . Cassia tora

1. Leaflets ovate to elliptic-oblong, usually acute, 6-20 in number; pods flattened, transversely segmented, 7-12 cm long.

   2. Flowers less than 3 cm across, in several-flowered (10-15) axillary racemes; leaflets acute, often more than 12.

      3. Pod segments considerably wider than long (see illustration); ovary appressed-hairy; petiolar gland scarcely stalked; stems and petioles glabrate or appressed-hairy. . . . . C. marilandica

      3. Pod segments not wider than long, ovary villous; petiolar gland clavate, stalked; stems and petioles with spreading pubescence. . . . . C. hebecarpa

   2. Flowers 3 cm or more in breadth, in reduced racemes, mostly 1-2 per leaf axil; leaflets acuminate, usually 10. . . . . C. occidentalis

Cassia hebecarpa Fern. (C. marilandica auth. non. L.; Ditremexa marilandica auth.) Wild Senna. Plate IV.
Plant perennial from rhizomes. Stems erect, often exceeding 1 m, sparsely pilose. Stipules acicular, ciliate, mostly deciduous on mature plants. Petiolar gland at base of petiole clavate to short-columnar. Leaves with 6-8 pairs of elliptic, mucronate leaflets. Inflorescences of many-flowered axillary racemes. Flowers 2-2.5 cm across, petals usually 3-veined. Ovary densely villous. Pods oblong, up to 1 dm in length, somewhat villous when young, the joints about as long as wide. Seeds brown, about 4 mm long, compressed, broadly obovate and about as wide as long. Hilum below a slight hook at proximal end.

Distribution and habitat—Eastern United States, west to Wisconsin, south to Tennessee and North Carolina, not found west of Mississippi River. Characteristic of bottom land, open woodlands, roadside thickets, scattered plants or extensive stands.

Phenology—Flowering July-August.

Variability—Var. longipila Braun from Kentucky possesses villous petioles.

Nomenclature—This species is the Cassia marilandica L. of older American botanical literature. Linnaeus' description did not satisfactorily distinguish between this and the following species which Shafer (1904) ultimately described as C. medsgeri. Fernald (1937), investigating material in the Linnaean herbarium disclosed that the pertinent Linnaean specimen represented the same species as Shafer's Cassia medsgeri. Linnaeus' citations were mixed, some apparently referring to his Cassia marilandica and some to the other species. Fernald preferred to give preference to the Linnaean specimen rather than plates of prior authors. Since no earlier epithet was available it was necessary to give a new name to the marilandica of authors, i.e., hebecarpa Fern. This interpretation has been accepted by most subsequent American authors except for Fassett (1939) who preferred to consider Linnaeus' C. marilandica as a mixture and to apply the doctrine of residues.

Discussion—Although this and the following similar species would appear to be closely related, I have seen no intermediates between the two. However, they are often confused, particularly in vegetative or early flowering condition. Young plants of Cassia hebecarpa can be distinguished by their pilosity (often largely destroyed on herbarium specimens) and the short-stalked petiolar glands. In flower, the strongly villous pistils can easily be discerned.

Deam (1940) notes that animals will not eat this or the following species.

Cassia marilandica L. [C. medsgeri Shafer; Ditremexa medsgeri (Shafer) Britton and Rose]. Wild Senna. Plate IV.

Similar to above species in habit. Stems and petioles glabrate or with appressed pubescence. Stipules narrowly lanceolate, not ciliate, usually absent on mature plants. Petiolar gland ovoid, scarcely stalked. Leaflets elliptic to elliptic-oblong, petals often 5-veined. Ovary appressed-hairy. Pods glabrate, segments much wider than long. Seeds obovate-oblong, narrowed and slightly hooked at base, about 5 mm long, 3 mm wide.

Distribution and habitat—Eastern Nebraska to western Pennsylvania, south to western Carolinas, northern Alabama, eastern Texas. Open woods, thickets, roadsides.

Phenology—Flowering August or latter part of July.

Discussion—This species is closely related to C. hebecarpa, but occurs west of the Mississippi as well as in the eastern states. Also it appears to be more widely distributed in the southern part of the country. It is said to tolerate poorer, drier soil than C. hebecarpa.

Cassia occidentalis L. [Ditremexa occidentalis (L.) Britton and Rose]. Coffee-weed. Plate VI.

Perennial but annual in our range. Stipules narrowly lanceolate. Leaflets mostly 5 pairs, glabrous, ovate to ovate-lanceolate, acuminate. Gland low, subglobose.

Racemes reduced, crowded, 1–3 flowered in upper leaf axils. Petals 1.5–2 cm long. Pods narrowly oblong, to 10 cm, often slightly falcate, with a lighter-colored nonsegmented margin. Seeds obovate, not hooked at base, faces nearly plane, about 4.5 mm long.

Distribution and habitat–Southern and eastern states north to Virginia and Iowa, west to Texas. Common in American and Old World tropics. Open waste areas, chiefly on disturbed land, often regarded as a weed.

Phenology–Flowering July and August in temperate areas.

Chromosome number–Gametic n = 13 (Muto, 1929; Senn, 1938b).

Cassia tora L. [Emelista tora (L.) Britton and Rose]. Coffee-weed. Plate V.

Plants small or robust, glabrate annuals. Leaflets (4)–6, obovate, the terminal the largest. Stipules linear-lanceolate, asymmetrically curved, ciliate, mostly persistent. Petiolar gland short-columnar, contiguous to lower leaflets. Flowers 2–3 in leaf axils, appearing congested at stem apex. Pods linear, arcuate, 10–15 cm long, 2–5 mm wide, nearly quadrate. Seeds ca. 4 mm long, obliquely oblong, somewhat pointed at hilar end; surface shiny, dark brown, often covered with glossy curving lines[1]; light colored areas on each side narrowly oblong.

Distribution and habitat–Southeastern and central states north to Virginia and Missouri, west to Texas, of sporadic occurrence farther north; widely distributed in tropical America as well as Old World. In the southern states common in low fields, open woods and roadsides. Flowering July-September.

In the north-central states, this species is established sparingly in southern Missouri and Illinois. It has been occasionally collected farther north but does not seem to persist.

Phenology–A summer annual, germinating any time from spring until frost, flowering July-October.

Chromosome number–Gametic n = 13 (Datta, 1933; Senn, 1938b); n = 14, with the hypothesis that one of "the thirteen bodies illustrated by Senn is a quadrivalent" (Jacob, 1940).

CERCIS L.

Small trees. Leaves simple, entire, cordate. Flowers appearing before leaves, in contiguous clusters on branchlets of previous season. Calyx shallowly lobed. Corolla irregular, papilionaceous in appearance. Stamens 10, separate. Pod oblong, flat, somewhat membranous.

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[1]Apparently caused by cracks and subsequent loosening of an external horny layer.

A distinct, geologically ancient, small genus, with two species in temperate America, five in eastern Asia, and one or two in southeastern Europe.

Chromosome numbers of somatic 12 and 14 have been reported for members of this genus (Atchison, 1949; Senn, 1938b).

Literature

Britton and Rose (1930, 201-202). North American species.
Fernald (1950, 886). Northeastern U.S.
Gleason (1952, 381-382). Central and eastern U.S.
Hopkins (1942). Monograph, U.S. species.

Cercis canadensis L. Redbud, Judas tree. Plate V.
Small tree with a wide crown. Leaves cordate, short-acuminate in most forms, palmately veined. Flowers stalked, pinkish, the fascicles very abundant, the whole tree appearing pinkish when in full bloom. Pods 6-10 cm long, purplish brown. Seeds elliptic to slightly obovate, plump but sides nearly plane, shiny dark brown, ca. 4.5 mm long.

Distribution and habitat–Eastern half of the United States, exclusive of the northeast corner, west to eastern Nebraska and Texas, south into Mexico. Less common north of Missouri and central Indiana. In cultivation and sparingly established beyond principal limits. Rich woodlands, ravines, and bottoms. Extensively used as an ornamental.

Phenology–Flowering for a 1-2 week period in spring, March to May.

Chromosome number–Somatic 12 (Senn, 1938b).

Variability–The redbud as we know it in the north-central states is reasonably consistent morphologically. Named variants include: f. glabrifolia Fern., leaves glabrate beneath rather than sparsely pubescent, and; f. alba Rehd., flowers white. By contrast, the redbuds of the Southwest (southern Oklahoma, Texas, and adjacent Mexico) possess thick, shiny leaves which tend towards a subreniform shape. They usually grow on dry uplands, limestone bluffs, and outcrops rather than lowlands. These redbuds are treated as geographical varieties of Cercis canadensis by Hopkins (1942). Most earlier workers had considered them separate species.

CHAMAECRISTA Moench (Cassia in part)

Shrubs or herbs, our species annuals. Leaves 1-pinnate, sensitive, with numerous small leaflets. Petiolar gland conspicuous, in our species depressed, saucer-shaped. Stipules nerved, persistent. Flowers solitary or 2-3 together, often strongly supra-axillary. Corolla irregular or nearly regular. Petals yellow. Stamens 5 or 10, various in length but all fertile. Filaments very short. Pods oblong, straight, flattened, elastically dehiscent. Seeds flattened, pointed at one end, alveolate-striate.

Chamaecrista has alternatively been regarded as a section of Cassia, or as a separate genus. It is herein treated as a genus. The major considerations are reviewed by Senn (1938a) and will not be repeated here.

The role of wild leguminous species in the revegetation of sterile or eroded areas has been discussed by several authors (e.g., Campbell, 1927; Isely, 1939). Such legumes may be dominant in the primary successional stages of revegetation and gradually disappear as site characteristics are improved and other plants invade the area. In this respect our native chamaecristas are pre-eminent. Throughout the south and south-central states they often occupy areas (especially abandoned farmland) which otherwise will support only a meager weed growth. After a few years, a more permanent vegetation gradually develops, and farming is again possible. On the other hand, in the absence of this natural leguminous cover, further deterioration of the site takes place.

The native chamaecristas are abundant seed producers. The harvest of seed should present no unusual difficulties although there is a strong tendency to shatter as maturity is reached. Limited harvesting and subsequent planting has been done for wild-game food and soil conservation purposes. The potentialities of the chamaecristas for agriculture, especially soil improvement, would appear to merit study.

Literature

Britton and Rose (1930, 270-299). North American species.
Fernald (1950, 885-886). Northeastern U.S.
Gleason (1952, 384-386). Central and eastern U.S.
Pennell (1917). Chamaecrista of U.S.
Senn (1938a). Cytology.

Key to Species

1. Flowers 2–3 cm in diameter; stamens 10; petiolar gland usually depressed; leaves usually with not more than 12 pairs of leaflets. . . . . Chamaecrista fasciculata

1. Flowers 1 cm or less in diameter; stamens 5; petiolar gland short-stipitate; leaves usually with more than 12 pairs of leaflets. . . . . C. nictitans

Chamaecrista fasciculata (Michx.) Greene (Cassia chamaecrista auth., non L.). Partridge Pea. Plate VII.
Stems finely or spreading pubescent. Leaflets oblong, glabrate, 10–13 (averaging about 11) pairs. Petiolar gland usually sessile, sometimes short-stalked. Stipules linear, closely nerved. Flowers 2–3 cm in diameter, nearly regular, on pedicels 1–2 cm long. Stamens 10, of various lengths, usually yellow; filaments much reduced. Pods 4–6 cm long, smooth or with inconspicuous, spreading pubescence. Seeds flattened, rectangular to rhomboidal, often obliquely pointed at base, black, about 3 mm long, lines of alveolae fairly distinct.

Distribution and habitat–Eastern half of the United States exclusive essentially of the northern tier of states and most of New England. West to southeastern South Dakota, eastern New Mexico, and Texas. Sporadic in occurrence in the northern part of its range in the north-central states and possibly introduced from the south.

This is one of the most common and showy summer legumes, growing along roadsides, waste areas, fields, and open woodlands. In our area it is usually found in sandy soil, but in the south occupies a wide variety of soil types. It appears to favor moister soils than Chamaecrista nictitans.

Phenology–In north-central states, flowering late July and August. In southern part of range, late May and throughout summer.

Chromosome number–Senn (1938a, 1938b) reports an n number of 8.

Nomenclature–For many years this species was referred to Cassia chamaecrista L. Pennell (1917) suggested a typification of C. chamaecrista, excluding our species, which has largely been accepted. Hence, the next available epithet Cassia fasciculata[1] Michx. was taken up. Chamaecrista camporum Greene may also be referred to C. fasciculata.

Variability – Like most widely distributed species, Chamaecrista fasciculata is variable morphologically. The more conspicuous variable characters include flower size and color, nature of pubescence, number and size of leaflets, size of the petiolar gland, and habit, i.e., erect or low ascending, branched or unbranched. Throughout the greater part of the range of the species this variability appears largely random; about the southern periphery, however, variability becomes geographically and ecologically oriented.

Named variants found in the north-central states include:

(1) Chamaecrista robusta (Pollard) Pollard. [Cassia fasciculata var. robusta (Pollard) McBride]. Plants averaging large. Pubescence (stems, pedicels, pods) spreading and often conspicuous. Occasional or common throughout much of range of species.

(2) Chamaecrista rostrata Wooton and Standl. [Cassia fasciculata var. rostrata (Wooton and Standl.) Turner]. Plants averaging lower and more branched; leaflets often reduced in number. Petiolar gland usually small. Eastern New Mexico, adjacent western Kansas and northwestern Texas.

(3) Cassia fasciculata f. jenseni Palmer and Steyer. White flowers.

The most common variant is Chamaecrista robusta which occurs sporadically throughout much of the range of the species. It has been treated as a separate entity by some workers and recognized as a geographical variety by others. Pennell (1917) stated that it occurs "throughout the lower Mississippi Valley, mostly in alluvial soil; also pushing up into the valleys of the southern Alleghenies," but in Louisiana where it was seemingly quite distinct from C. fasciculata, "shows a surprising number of intermediates." Fernald (1940) echoed the thought that it was primarily of Mississippi drainage.

Over a period of years the author has examined numerous populations of Chamaecrista fasciculata in the field for the presence of the robusta

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[1]Incorrectly cited as fascicularis by Greene (Pittonia 3:242. 1897) in making the transfer to the genus Chamaecrista.

element. This form has been observed in various parts of the range of the species, and is certainly not localized in the lower Mississippi Valley. One occasionally encounters populations which are largely of the robusta type. More frequently, however, plants exhibiting robusta characteristics—with some or considerable spreading pubescence—occur interspersed among those with incurved hairs.

In an attempt to obtain further information concerning the geographical orientation of Chamaecrista robusta, several hundred sheets of the fasciculata-robusta complex were examined in the herbarium. It was soon evident that the material could not easily be sorted into two reasonably discrete groups. There were numerous intermediates, for example: (1) plants with a mixed stem pubescence, including both incurved and spreading hairs, and (2) forms in which stem pubescence was of incurved hairs but those on the pedicels were all spreading. Furthermore, specimens with exclusively spreading pubescence ranged from shaggy villous forms to those with but a scant indumentum. No geographical orientation of these various types could be discerned; possibly a greater proportion of the plants from the lower Mississippi Valley were of the spreading pubescent type.

It may be suggested that (a) there is no sharp distinction between Chamaecrista fasciculata and C. robusta (whether as species or varieties);[1] the variation is probably multifactorial and various combinations may occur; (b) C. robusta is not geographically identifiable nor does it appear to represent a specific ecotype; (c) however, gene distribution in regard to the characters involved is not uniform; hence population modes may differ in different parts of the range.

Chamaecrista rostrata Wooton and Standley was described from Logan, New Mexico, and Gates (1940) refers southwestern Kansas specimens of Chamaecrista to this species rather than to C. fasciculata.

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[1]Possibly it would be appropriate to transfer robusta (Pollard) to subordinate status under Chamaecrista fasciculata (this has been done in the genus Cassia but not Chamaecrista). However, the present author questions, as a practice, the advisability of burdening legal nomenclature with names for minor subspecific categories—forms exhibiting little geographic or ecological orientation within the species. It seems quite proper that well marked geographic varieties should be given recognition in accordance with the Rules of Nomenclature; such varieties are usually of interest to any student of plants, and often possess obvious significance in the evolution of the group involved. But the application of such names to local races or recurring phenotypic combinations appears absurd. Most widely ranging species possess dozens of reasonably discernible forms; if some of them deserve names, consistency should decree naming them all. Such consistency has been attempted in some European monographic studies with appalling nomenclatural results. Furthermore, minor subspecific categories are usually of primary interest only to a few specialists, especially geneticists. Is it not more conveneient for all concerned for these individuals to devise their own systems of nomenclature to meet the case in hand, as the geneticists have done for Zea and Drosophila? . . . New combinations for the groups herein under discussion are not attempted.

Tidestrom and Kittell (1941) recognize both species in New Mexico. Through kindness of the Curator of the Herbarium of Kansas State College it has been possible to examine the Kansas material. The specimens have been assigned to C. fasciculata. Perhaps they should be accorded varietal status as Turner (1955) has recently done. Undoubtedly, C. fasciculata as represented in the more arid reaches of the Great Plains in southwestern Kansas, adjacent Oklahoma and Texas differs physiologically from its more mesophytic congeners; however, correlative morphological differentiation appears difficult to determine except possibly on a clinal basis.

The Chamaecrista fasciculata complex exhibits further, and more extensive, variability through much of the southern coastal plain and in Texas. The forms involved do not occur in the north-central states and have not been considered in the present study.

Discussion—This species and the following are similar vegetatively, although the leaves of Chamaecrista fasciculata are somewhat the larger and coarser. To estimate the degree to which vegetative specimens might be distinguished by leaf characters in the north-central states, observations were made on leaves of twenty-five specimens. These specimens were taken at random throughout the north-central area.

	C. fasciculata	C. nictitans
No. of leaflets:		
Range	10–13 pairs	11–19 pairs
Average	11 pairs	16 pairs
Length of leaflets:		
Range	5–6.5 mm	2.5–6.5 mm
Average	5.5 mm	4.5 mm
Width of leaflets:		
Range	3–4.5 mm	1.5–2.5 mm
Average	3.5 mm	2.0 mm

Chamaecrista fasciculata furnishes food and cover for wild life, and has been given limited trial for soil conservation purposes. In the southeastern states it is said to be an important source of honey, the nectar being obtained not from the flowers but the petiolar glands (Graham, 1941).

Chamaecrista nictitans (L.) Moench. [(C. procumbens (L.) Greene]. Plate VII.

Petiolar gland stalked. Leaflets 11–19 pairs. Flowers less than 1 cm broad, irregular with one petal larger than others, on short pedicels 2–4 mm in length. Stamens five, irregular in length; anthers reddish; filaments distinct. Pods 3–4 cm long, appressed-hirsute except as noted below. Seeds similar to those of C. fasciculata, but alveolae less distinct.

Distribution and habitat—Southern and eastern states, north to Massachusetts, west to Kansas and Texas. In our area, Illinois, Indiana,

Missouri, and southeastern Kansas. Rare or scattered in northern portion of range, possibly introduced, abundant and conspicuous to the south. Rocky woods, fields, waste areas, roadsides, usually in open, dry, sandy areas.

Phenology–Flowering, northern portion of range, latter part of July to end of season. In the southern coastal plain may begin to flower as early as end of May.

Chromosome number–Senn (1938a, 1938b) reports an n number of 8 for Chamaecrista procumbens (presumably Chamaecrista nictitans).

Nomenclature–The name Chamaecrista procumbens (L.) Greene has been employed by several authors with reference to this species. Cassia nictitans and procumbens were simultaneously published by Linnaeus (Sp. Pl. 380, 1753). Although C. procumbens has been subject to several interpretations, it seems possible that it represents the same species as C. nictitans (Pennell, 1917). If a justification for continuing the classical employment of the epithet nictitans in the genus Chamaecrista is required, it may be based (Lanjouw, 1956; Article 64) on the fact that it was adopted and appropriate transfer made in 1794 (Moench. Meth. 272). The epithet procumbens was apparently not taken up until 1899 (Greene, Pittonia 4:28).

Variability–Described variants are based on pubescence forms. The widespread typical species has short, incurved hairs on the stems and fruits. Variety leiocarpa Fern.[1] possesses glabrous fruits; Indiana and Kentucky. Variety hebecarpa Fern. possesses villous fruits; coastal Virginia and South. Chamaecrista mohrii (Pollard) Small, and C. aspera (Muhl.) Greene of the southeastern coastal plain both have villous fruits and hairy leaves. C. multipinnata (Pollard) Greene has numerous leaflets. These species should possibly be regarded as further variants of C. nictitans, but have not been included in the present study.

Discussion–Isely (1939) reported that Chamaecrista nictitans seemed to tolerate drier soil than C. fasciculata. Subsequent observations have suggested that it is one of the primary invaders of run-down abandoned fields in the south. It gradually disappears in later successional stages. It is possible that the ability of this plant to thrive in dry, sterile soils should render it worthy of consideration in soil improvement projects. Graham (1941) comments that it has been used in mixtures with annual lespedezas for soil conservation purposes.

GLEDITSIA L.

Trees, usually thorny. Leaves once or twice pinnate. Flowers in short, catkin-like axillary racemes, regular, greenish, usually unisexual. Hypanthium short. Perienth segments 6–10, essentially similar. Stamens 10 or fewer. Pods large, flattened, nearly indehiscent.

The species of Gleditsia, about ten, are indigenous to diverse geo-

[1]Under Cassia. Appropriate combinations under Chamaecrista are not being made.

graphical areas: North America, South America, Asia, and Africa. Two species are native to the central United States.

Atchison (1947, 1949) has found a somatic chromosome number of 28 in 7 species investigated.

Gleditsia has often been represented as one of the more ancient leguminous genera. Fossil remains very similar to present day Gleditsia (Gleditsiophyllum) date back to the upper Cretaceous and Eocene. It is perhaps reasonable to postulate antiquity for the group on the basis of geological evidences as well as floral morphology and geographical relationships, but the same arguments could be presented for several other leguminous genera. However, Atchison (1949) has held that cytological evidence further suggests the "relic" nature of the genus. Of the species investigated, all were believed to be polyploids. It was, therefore, reasoned that the present species must have been derived from still more ancient, diploid ancestors which are now extinct.

Literature

Atchison (1947 , 1949). Cytology.
Britton and Rose (1930, 302-303). North American species.
Fernald (1950, 885). Northeastern U.S.
Gleason (1952, 382). Central and eastern U.S.

Key to Species

1. Pods oblong, 2–4 dm long, several-seeded; thorns usually branched; trees of various habitats. . . . . Gleditsia triacanthos

1. Pods ovate to ovate-oblong, 2–5 cm long 1 (2–3)-seeded; thorns usually simple; trees of swampy areas, southeastern portion of our range. . . . . G. aquatica

Gleditsia aquatica Marsh. Water locust. Plate IX.
A small tree, similar to the honey locust in appearance. Twigs orange-brown. Thorns usually simple. Basal portion of pod drawn out in a long stipe, the body ovate, generally not more than 5 cm long, usually 1-seeded, without pulp. Seeds broadly elliptic, flattened, about 13 x 10 mm across.

Distribution and habitat–Southeastern coastal plain, locally north in Mississippi Valley to southern Indiana and Illinois. Swamps, sloughs and along rivers.

Phenology–Flowering June.

Gleditsia triacanthos L. Honey locust. Plates VIII and IX.
Medium to large trees, usually with branched thorns. Twigs reddish-brown. Leaves of two types: bipinnate on elongate branchlets; once-pinnate, clustered on spurs. Leaflets oblong-elliptic. Flowers yellowish-green. Pods velvety-pubescent when young, very large,

up to 40 cm in length, oblong, flat, often curved and twisted, with a sugary pulp. Seeds elliptic-oblong, about 9 x 4.5 mm in length and width.

Distribution and habitat–Central United States east to the Appalachians, west to eastern Nebraska and Texas.

Grown as a shade tree, the honey locust is cultivated, especially in the eastern states, and naturalized beyond its native limits. The honey locust favors wet soil but in the western states occurs in upland as well as bottom woodlands. In the eastern portion of its range it tends to be limited to river bottoms.

Phenology–Flowering May to June. The fruits are well developed by the latter part of July and are often persistent to the following season.

Chromosome number — Somatic 28 from a number of collections throughout range (Atchison, 1947).

Variability–Although, proverbially, the thorniest of our native trees, the development of thorns varies widely on different trees. Some individuals are almost completely covered, trunk and branches, with long, branched thorns. At the other extreme, thorns are almost completely lacking on the "smooth" form[1] which is widely employed in cultivation. Deam (1940) states that the thornless honey locust has nonpulpy pods and smaller seeds than the typical species. When planted, seeds of the smooth honey locust, according to this same author, produce about 60 per cent thornless seedlings.

A rare type with pods about 2 dm long (x Gleditsia texana Sarg.) is reputed to be a hybrid between this and the preceding species. Occurring in southwestern Indiana, it is treated by Deam (1940) as a third species. Deam reports finding a specimen with hundreds of seedlings under it, stating "if this form is a hybrid it is a fertile one."

Discussion–The two-leaf types borne by the honey locust are often strikingly different in appearance; the bipinnate ones usually have numerous, small leaflets; the once-pinnate types possess considerably larger, and relatively few leaflets. The arrangement of the leaflets and pinnae is often irregular or almost entirely alternate on the rachis.

Blaser (1956) has recently investigated the morphology of Gleditsia thorns. Supra-axillary in position, the thorn represents a reduced, determinate branch system. The common type is monopodial and three-parted.

McDougall (1921) described peculiar thick-walled root hairs characteristic of Gleditsia triacanthos and, to a lesser extent, of Cercis canadensis and Gymnocladus dioica. Since such structures are sometimes found on desert plants, this author suggests that the thick-walled hairs (as well as the thorns) are relics of a period when Gleditsia grew under xerophytic conditions.

Besides being a popular ornamental, the honey locust is planted for erosion control in steep wooded areas, and for windbreaks. The leaves are often browsed by stock, and the pods are said to be valuable animal food. The wood is locally employed for fence posts and railroad ties.

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[1]Usually termed forma inermis, but it now appears that this name cannot properly be employed.

GYMNOCLADUS Lam.

Trees. Leaves bipinnate, exceedingly large, with ovate leaflets. Flower racemes terminating short branchlets. Perianth regular, of 10 segments arising at apex of a tubular hypanthium. Stamens 10, of two lengths. Pods very large, woody, indehiscent.

Gymnocladus includes two species only, one each of temperate America and Asia.

Literature

Britton and Rose (1930, 304). North American species.
Fernald (1950, 884-885). Northeastern U.S.
Gleason (1952, 382). Central and eastern U.S.

Gymnocladus dioica (L.) K. Koch. Kentucky coffee-tree.
A large tree with thick branchlets, dioecious or polygamous. Ultimate leaflets ovate, about 1 dm long. Flowers racemed, whitish-green. Pods reddish-brown, 6-15 cm in length, with sugary pulp. Seeds very large, 1-2 cm across, and nearly 1 cm thick.

Distribution and habitat—Central and east-central United States west to eastern Oklahoma and Nebraska, north to central Wisconsin and eastern New York. Cultivated and sparingly naturalized considerably beyond these limits, especially on eastern coastal plain. Rich bottom woodlands, ordinarily not abundant, in many places nearly exterminated.

Phenology—Flowering May-June, the pods often persistent until the next year.

Chromosome number—Somatic 28 (Atchison, 1949).

Discussion—The gigantic leaves are irregularly divided, and no two are alike. Often there are one or two ovate leaflets on the main rachis below the first compound pinnae, which in turn possess fewer leaflets than the pinnae above. The pinnae may be even- or odd-pinnate. The leaflets are usually mostly irregularly alternate.

Deam (1940) notes that this tree is capable of sending up root suckers.

HOFFMANSEGGIA Cav. (Larrea Ortega)

Herbs or low shrubs, often glandular. Leaves bipinnate. Leaflets numerous, small. Stipules inconspicuous. Inflorescence a simple raceme. Petals 5, slightly irregular. Stamens 10. Pods flat, often short, and somewhat curved.

This genus centers primarily in the southwestern states and adjacent Mexico. Two species enter the southwestern extremity of our area.

Larrea Ortega, 1797, has been taken up for this genus by several authors. Larrea Cav. is now conserved for a genus in the Zygophyllaceae; hence, Ortega's name cannot be used for our leguminous genus. Hoffmanseggia is the earliest available name.

Literature

Britton and Rose (1930, 309-316). North American species (as Larrea).
Fisher (1892). North American species.

Key to Species

1. Leaves black-dotted; petals scarcely exceeding sepals. . . . . Hoffmanseggia jamesii

1. Leaves not black-dotted; petals exceeding calyx, the claws with stalked, brownish glands. . . . . H. densiflora

Hoffmanseggia densiflora Benth. ex Gray (H. falcaria Cav.). Plate VI.
Plants perennial, caespitose from slender rootstocks. Stems subscapose to ascending-leafy. Stipules ovate-scarious, inconspicuous. Lower leaves clustered, with 5-6 pairs of pinnae; upper leaves mostly with 2-3 pairs of pinnae. Petiole and rachis with brownish, stalked glands. Leaflets small, broadly oblong, with no venation. Inflorescence terminal, often sinuous. Axis with pubescence and stalked glands. Calyx glandular. Petals well exceeding calyx, the long claws densely covered with stalked glands. Pods 2-4 cm long, oblong, straight or falcate. Seeds moderately compressed, obovate, slightly hooked at base, dull olive-drab brown, 3.5 x 2.5 mm.

Distribution and habitat–Southwestern United States, Texas to southern California, northeast to Morton County, Kansas. Open prairies, roadsides, fields, often forming conspicuous colonies, becoming a weed in irrigated areas in Arizona and California.

Phenology–Flowering principally June-July but continuing throughout the summer.

Nomenclature–The names Hoffmanseggia densiflora Benth. ex Gray and the earlier H. falcaria Cav. have been employed for this species. The application of H. densiflora is based upon the taxonomic exclusion of the South American elements constituting H. falcaria–believed by Fisher (1892) to be conspecific with H. densiflora.

Hoffmanseggia jamesii T. and G. Plate VI.
Plant perennial from a woody crown extending from a deep, fusiform root. Stems caespitose, low spreading, usually zigzag, black-glandular and finely hairy. Stipules persistent, scarious, oblong-lanceolate. Leaves conspicuously black-dotted, finely canescent; pinnae

usually 2-3 pairs, plus an odd one; leaflets small, 3-4 mm long. Racemes terminal or subterminal, 5-15 flowered. Petals scarcely exceeding sepals, the upper red-dotted. Pods horizontal to pendant, lunate, 1.5-2 cm long, about 3-seeded, black-glandular and with branched pubescence. Seed flat, asymmetrically obovate to nearly circular, about 5 mm across.

Distribution and habitat—Southwestern Nebraska to Texas, west to Arizona. Dry plains, desert grassland and in sagebrush, usually sandy soil.

Phenology—Flowering early summer but continuing to some extent throughout the season.

Rejected Species and Synonyms

The following list includes:

(1) Species erroneously reported from the north-central United States as a consequence of misidentification or incorrect application of names.

(2) Names employed in recent (last 30 years) botanical manuals herein rejected on nomenclatural or taxonomic bases.

Acacia hirta Nutt. ex T. and G.
Treated as _Acacia angustissima_ var. _hirta_ (Nutt. ex T. and G.) Robinson.

Acaciella Britt. and Rose
Segregate from _Acacia_.

Acaciella hirta (Nutt. ex T. and G.) Britt. and Rose
Herein considered as _Acacia angustissima_ var. _hirta_ (Nutt. ex T. and G.) Robinson.

Acuan Medic.
Synonymous with _Desmanthus_ Willd., the latter conserved.

Algarobia (DC.) Benth.
As a genus, included within _Prosopis_ L.

Cassia chamaecrista L.
As employed by authors, not Linnaeus, equivalent to _Chamaecrista fasciculata_ (Michx.) Greene.

Cassia fasciculata Michx.
Chamaecrista fasciculata (Michx.) Greene.

Cassia medsgeri Shafer
Synonymous with _Cassia marilandica_ L.

Cassia nictitans L.
Chamaecrista nictitans (L.) Moench.

<u>Chamaecrista rostrata</u> Wooton and Standl.
Considered as a race of <u>Chamaecrista fasciculata</u>, see discussion under latter in text.

<u>Desmanthus cooleyi</u> (Eaton) Trel.
Reported from Nebraska by Rydberg (1932). Winter (1936) indicated that there were no specimens in the Nebraska University herbarium. I have seen no material from the north-central states.

B.L. Turner (personal correspondence) has examined two sheets of <u>Desmanthus cooleyi</u> in the New York Botanical Garden as follows: "Rydberg, Central City, Nebraska, June 27, 1895.; Carleton 359, Cinairon Valley, July 31, 1891." (The latter locality is probably Cimarron). Turner states "All of the rest . . . which I examined from New York and U.S. National Herbaria were from Texas, New Mexico, Arizona and Mexico."

It may be suggested that (1) <u>D. cooleyi</u> was once of sporadic occurrence north of its present range and that the stations have since been destroyed, or that (2) mistakes were made in recording collection locality on the above two sheets. In either event, there appears to be no 20th century collections from the north-central states.

<u>Ditremexa</u> Raf.
Segregate from <u>Cassia</u> L.

<u>Emelista</u> Raf.
Segregate from <u>Cassia</u> L.

<u>Gleditsia texana</u> Sarg.
A form intermediate between <u>G. triacanthos</u> L. and <u>G. aquatica</u> Marsh, possibly of hybrid origin.

<u>Hoffmanseggia falcaria</u> Cav.
As employed by North American authors, synonymous with <u>H. densiflora</u> Benth. ex Gray. See text discussion.

<u>Larrea</u> Ortega
Synonymous with <u>Hoffmanseggia</u> Cavanilles. See text discussion.

<u>Leptoglottis</u> DC.
Synonymous with <u>Schrankia</u> Willd.; published at a later date and therefore superfluous.

<u>Morongia</u> Britton
Synonymous with <u>Schrankia</u> Willd.; published at a later date and therefore superfluous.

<u>Neltuma</u> Raf.
Synonymous in part with <u>Prosopis</u> L.; treated as a segregate genus by some authors.

Prosopis articulata Wats.
Synonymous with P. juliflora (Swartz) DC.

Prosopis chilensis (Mol.) Stuntz
A South American species treated as conspecific with P. juliflora (Swartz) DC. by some authors.

Prosopis glandulosa Torr.
Regarded as a form of P. juliflora (Swartz) DC.

Prosopis velutina Woot.
Regarded as a form of P. juliflora (Swartz) DC.

Schrankia nuttallii (DC.) Standl.
Synonymous with Schrankia uncinata Willd.

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PLATE I. ACACIA AND ALBIZZIA

Acacia angustissima. 1. Flower 8.5X. 2. Inflorescence (only lower pinnae of subtending leaf included) 1X. Albizzia julibrissin. 3. Flowering branch 1/3 X.

PLATE II. DESMANTHUS

Desmanthus illinoensis. 1. Inflorescence and subtending leaf 4/5X. 2. Fruit cluster 4/5X. 3. Gland between basal pair of pinnae 5 3/5 X. Desmanthus leptolobus. 4. Fruit cluster 1 1/5X.

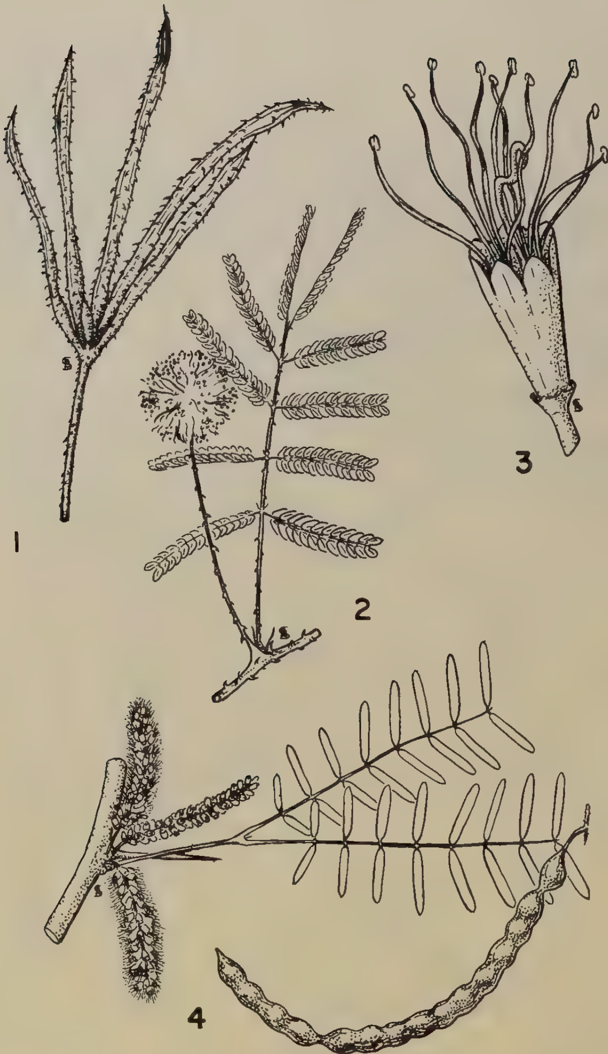

PLATE III. SCHRANKIA AND PROSOPIS

Schrankia uncinata. 1. Fruits 3/5X. 2. Inflorescence and subtending leaf 5 2/5X. 3. Flower 3/5X. Prosopis juliflora. 4. Inflorescence, leaf and fruit 2/5X.

PLATE IV. CASSIA

Cassia marilandica. 1. Leaf and inflorescence 3/5X. 2. Pistil 4 1/2X. 3. Mature pod 3/4X. 4. Petiolar gland 11 1/4X. Cassia hebecarpa. 5. Petiolar gland 11 1/4X. 6. Pistil 4 1/2X. 7. Mature pod 3/4X.

PLATE V. CASSIA AND CERCIS

Cassia tora. 1. Leaf and inflorescence 3/5X. Cercis canadensis. 2. Flower cluster 1 1/5 X. 3. Leaf and pod 3/5 X.

PLATE VI. CASSIA AND HOFFMANSEGGIA

Cassia occidentalis. 1. Leaf and inflorescence 2/3X. Hoffmanseggia jamesii. 2. Leaf and inflorescence 2/3X. Hoffmanseggia densiflora. 3. Habit 2/3X.

Chamaecrista fasciculata. 1. Branch with flowers and fruit 2/3X.
Chamaecrista nictitans. 2. Flowering branch 2/3 X.

PLATE VIII. GLEDITSIA

Gleditsia triacanthos. 1. Once-pinnate leaves arising from spur 2/3X.
2. Twice pinnate leaf from elongate shoot 2/3X.

PLATE IX. GLEDITSIA

Gleditsia triacanthos. 1. Fruit 2/5X. Gleditsia aquatica. 2. Fruits 1/2X.

PLATE X. *GYMNOCLADUS*

Gymnocladus dioica. 1. Flowers 3/5X. Leaf 1/3X. 3. Fruit 1/3X.

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SOME SIMPLE MATHEMATICAL MODELS AS AIDS IN INTERPRETING THE EFFECT OF FISHING[1]

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ABSTRACT

It is suggested that the possible effects of fishing on fish populations and catch can be studied with models involving mathematics no more complicated than simple algebra. In Model A, similar to that of Baranoff, populations accumulate to improbable magnitudes at low mortality rates. A Model C is proposed in which the population remains near a carrying capacity and recruitment, growth, and natural survival decrease as the population exceeds carrying capacity. Both numbers and poundage of fish in the catch increase as fishing pressure increases with Model C, whereas the Model A poundage reaches its peak with fishing mortalities of about 20 per cent unless the natural mortality rate is over 40 per cent. The numbers of large walleyes reach their peak in the catch with fishing mortalities of about 15 per cent in Model A and of about 45 per cent in Model C. If it is assumed that catch-per-unit effort is proportional to population density, the number caught per unit effort is at the minimum in Model C with fishing mortalities of 30–40 per cent and at highest fishing mortality rates with Model A. Fish populations do not have the extreme adaptability assumed for Model C, but limits tried with additional models, E and F, indicated that the adaptability must be considerably restricted to affect the general results in Model C.

INTRODUCTION

The effect of fishing upon fish populations and the subsequent catch is one of our most important problems and yet one on which we have little information or basic understanding.

Mathematical models have been used rather extensively by some biologists working with marine fisheries (e.g., Baranoff, 1918; Beverton, 1954; Dickie and McCracken, 1955; Ricker, 1948; Schaefer, 1954; Tester, 1955; and Thompson, 1937). The degree to which these mathematical models apply to actual fish populations has been questioned (e.g., Burkenroad, 1946; Watt, 1955).

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By setting up relationships which seem to be sound on the basis of what we understand about populations at present, and by computing what would happen with different natural and fishing mortality rates, we can determine what the effect of fishing might be. We can then observe fisheries to determine wherein the mathematical models fail to reflect the situation in the true population. The use of mathematical models may indicate the types of data that are needed to determine which model most faithfully represents the population changes.

The mathematical models which I have used in the present paper are designed specifically to study the effects of fishing. The mechanics of adjustment within the populations are only suggested. The models are based upon simple arithmetic, with a few algebraic relationships. Short cuts would be possible through the use of calculus.

The average age class composition of a population is a function of the mortality rates. In the models which follow, the annual mortality rate is assumed to be constant after the fish are one year old, except that in some models the natural mortality rate is assumed to double after the fish reach 10 years of age. The age class composition for any mortality rate can then be computed simply by starting with 1000 fish at age I and subtracting the annual mortality year by year until the year class disappears.

Examples were worked out with various annual mortality rates from natural causes (n) and from fishing (m) (Symbols as in Ricker, 1948). The total annual mortality rate (a) is then equal to n+m-nm, since some of the fish which are caught would have died from natural causes within the year and vice versa. The annual catch is then $\frac{m}{n+m}$ a.

The use of annual mortality rates in this fashion is just an approximate method. Ricker (1948, pp. 2-5) and others have shown that more accurate results may be secured by the use of "instantaneous" rates. To keep the mathematics of the models in the present paper as simple as possible, however, the annual mortality rates were used. The general conclusions of the models would not differ greatly if instantaneous rates had been used for mortality and for growth. The concept of instantaneous rates is a little more difficult to grasp, but Ricker (1948, pp. 98-101) presents tables whereby instantaneous rates could have been used in the present models as readily as the annual rates.

The biological data for the various models were largely taken from a study of walleyes, Stizostedion vitreum (Mitchill) of Clear Lake, Iowa (Whitney, 1955). The general form of the curves described for the various models would be much the same with any species of fish with similar life span. The average growth of Clear Lake walleyes was .3006, .3938, .6493, .6126, .8625, .50, and .7433 pounds for the first through seventh years consecutively. For the basis of our models we assume that the annual growth in later years is 0.625 pounds. Whitney's results suggest that the average annual mortality rate among the adult walleyes in Clear Lake is about 35 to 50 per cent. The fishing mortality was estimated from tag returns as 15.7 per cent in 1952 and as 6.3 per cent in 1953.

The relationship between total length and weight was found to be quite adequately described by the formula:

$$\text{Log } W = -2.370 + 3.0907 \text{ Log } L.$$

where W is the weight in ounces
and L is the total length in inches.

As a convenience, the models are labelled by letters. The letters themselves have no significance and some models which were studied are not included in this report.

Model A

The first model that we will try is one similar to that used by Thompson (1937) and Baranoff (1918). We start with an annual recruitment to age group I of 1000 fish. If we assume that there is an annual natural mortality of 25 per cent and an annual fishing mortality of 20 per cent, we can trace the history of each group of 1000 fish and determine how many survive to various ages and how many are caught by fishermen (Table 1).

Table 1. Estimated catch of walleyes from one year class in Clear Lake with an assumed annual natural mortality of 25 per cent and a fishing mortality of 20 per cent for fish over 9 inches total length.

Age group	Number of fish: At beginning of year	Number of fish: Total mortality	Number of fish: Catch	Catch in pounds
I	1000.0	355.0	127.4	46.2
II	645.0	258.0	114.7	79.6
III	387.0	154.8	68.8	92.5
IV	232.2	92.9	41.3	80.8
V	139.3	55.7	24.8	69.9
VI	83.6	33.4	14.8	49.1
VII	50.2	20.1	8.9	36.2
VIII	30.1	12.0	5.3	24.8
IX	18.1	7.2	3.2	17.0
X	10.9	4.4	2.0	11.9
XI	6.5	2.6	1.2	7.9
XII	3.9	1.6	0.7	5.0
Subtotals			413.1	520.9
XIII	2.3	0.9	0.4	3.1
XIV	1.4	0.6	0.3	2.5
XV	0.8	0.3	0.1	0.9
XVI	0.5	0.2	0.1	1.0
XVII	0.3	0.1		
Total			414.0	528.4

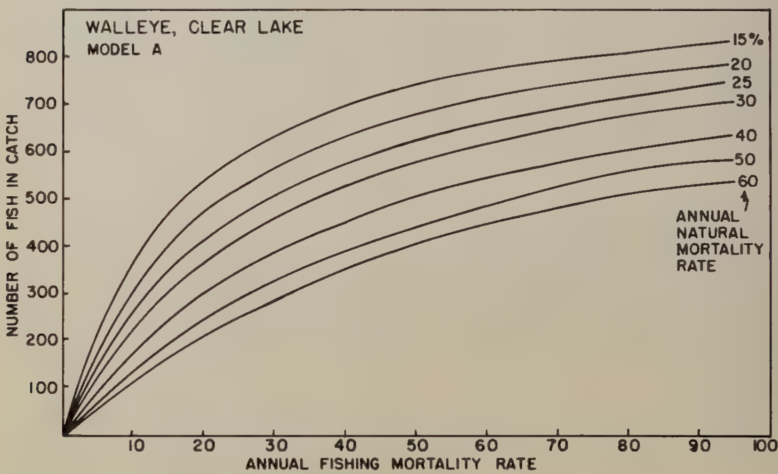

Fig. 1. Numbers of walleyes caught with different annual fishing mortality rates and with annual mortality rates of 15 to 60 per cent, according to conditions of Model A.

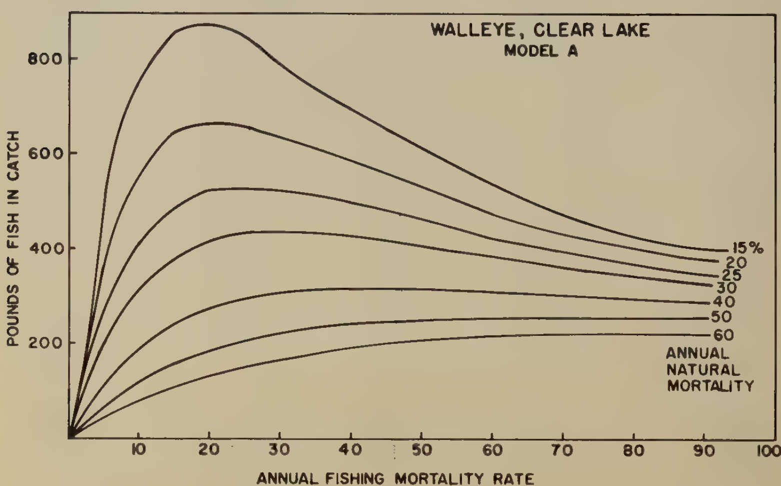

Fig. 2. Pounds of walleyes caught with different annual fishing mortality rates and with annual natural mortality rates of 15 to 60 per cent, according to conditions of Model A.

We assume that fish under 9 inches total length are not caught by anglers and thus are not subject to fishing mortality. Since only 70 per cent of age group I were over 9 inches the fishing mortality in age group I is only 0.7 that of the other age groups.

A subtotal is provided following age group XII. Very few walleyes over 12 years old have ever been examined and it is doubtful that they could accumulate the way they would theoretically with low total mortality rates in this model. It may be better to assume a total mortality following age XII. Data including all age groups are given in Figs. 1 and 2 but elimination of all fish over age group XII does not greatly affect the curves. The maximum effects are on the 15 per cent natural mortality curve where at 5 per cent fishing mortality 196 pounds of the catch were over age group XII and at 15 per cent fishing mortality, 98 pounds were over age group XII.

The same procedure may be used with other combinations of natural and fishing mortality rates and curves representing the catch can be drawn (Figs. 1 and 2).

Obviously the total number of fish caught from a given year class (the original 1000) will increase as the fishing mortality (or fishing pressure) increases with the natural mortality held constant (Fig. 1). Also, the lower the natural mortality rate, the greater will be the catch with a given fishing pressure. Increasing the fishing rate has a greater effect on the numbers of fish caught when the fishing rate is under 25 per cent than when it is somewhat higher.

The total poundage caught under various combinations of mortality is perhaps even more instructive than total numbers (Fig. 2). The maximum poundage in the catch with various natural mortality rates will be secured with fishing rates about as follows:

Natural mortality rate	Fishing rate for maximum catch
15%	20%
20%	22%
25%	25%
30%	30%
40%	40%

Increasing the fishing rate, as long as it is below that indicated for the natural mortality rate, will result in increased poundage in the catch. Further increases beyond that point will result in decreased poundage in the catch. It will be noted, however, that the changes in the total weight of the catch after fishing mortality rates of 30 per cent are reached are rather slight.

Model A assumed that the population can accumulate almost indefinitely. The accumulated populations computed with the lower annual mortality rates are unrealistic. Furthermore, Model A neglects any compensations in natural mortality, growth, and recruitment which may take place when the fishing mortality is changed.

MODEL C

We know that each body of water has a carrying capacity, or an ability to support a fairly definite poundage of fish. This carrying capacity may be a rather flexible one and may not be constant from year to year, but is believed to be fairly constant as long as there are no major changes in the habitat. The age class composition of Clear Lake walleyes in recent years corresponds quite well with that resulting from a 49 per cent total annual mortality in Model A. Since the total population resulting from an annual recruitment of 1000 fish in that example was 2000 pounds, we took 2000 pounds as the carrying capacity corresponding to the "normal" recruitment of Model A.

As the population is reduced below the carrying capacity, the growth rate of the individual fish increases, the recruitment increases, and the natural mortality rate decreases. When the population is above the carrying capacity, the trends are reversed. The average annual recruitment needed to maintain a standing crop of 2000 pounds of walleyes was determined for various mortality rates as follows (Table 2):

Table 2. Mean annual recruitment needed at different mortality rates to provide 2000 pounds of walleyes standing crop, and resulting population. Growth remaining at present average.

Age group	Numbers of fish at beginning of each year with different rates of mortality*									
	90%	80%	70%	60%	50%	40%	30%	25%	20%	15%
I	5212.0	3886.0	2786.0	1896.0	1222.0	740.0	420.0	302.0	208.0	131.0
II	521.2	777.2	835.8	758.4	611.0	444.0	294.0	226.5	166.4	111.4
III	52.1	155.4	250.7	303.4	305.5	266.4	205.8	169.9	133.1	94.6
IV	5.2	31.4	75.2	121.3	152.8	159.8	144.1	127.4	106.5	80.5
V	0.5	6.2	22.6	48.5	71.4	95.9	100.8	95.6	85.2	68.4
VI	0.1	1.2	6.8	19.4	35.7	57.5	70.6	71.7	68.2	58.1
VII		0.2	2.0	7.8	17.8	34.5	49.4	53.8	54.5	49.4
VIII			0.6	3.1	8.9	20.7	34.6	40.3	43.6	42.0
IX			0.2	1.2	4.5	12.4	24.2	30.2	34.6	35.7
X				0.2	1.1	3.7	9.7	15.1	20.8	25.0
XI					0.3	1.1	3.9	7.6	12.5	17.5
XII					0.1	0.3	1.5	3.8	7.5	12.2
XIII						0.1	0.6	1.9	4.5	8.6
XIV							0.2	0.9	2.7	6.0
XV							0.1	0.5	1.6	4.2
XVI								0.2	1.0	2.9
XVII								0.1	0.6	2.1
XVIII									0.3	1.4
XIX									0.2	1.0
XX									0.1	0.7

*After age X mortality rate doubles or survival rate is cut in half, whichever is smaller.

$$2000 = rw_1 + srw_2 \ldots + s^{n-1}rw_n$$

where r = number of age group I recruited

w_1, w_2, etc. = mean weight of walleyes in age I, II, etc.

$s = 1 - a$

We then assumed arbitrarily that recruitment deviated only one-half as much from "normal" and that growth rate changes will provide the rest of the adjustment. The degree to which the growth rate will be affected can then be determined as follows (Table 3):

Table 3. Age distribution of walleyes if the deviation from an annual recruitment of 1000 fish is only one-half that of Table 2. The factors that the growth must be multiplied by to maintain the standing crop at 2000 pounds.

Age group	Numbers of fish at beginning of each year with different rates of mortality									
	90%	80%	70%	60%	50%	40%	30%	25%	20%	15%
I	3106.0	2443.0	1893.0	1448.0	1111.0	870.0	710.0	651.0	604.0	566.0
II	310.6	488.6	567.9	579.2	555.5	522.0	497.0	488.3	483.2	481.1
III	31 1	97.7	170.4	231.7	277.8	313.2	347.9	366.2	386.6	408.9
IV	3.1	19.5	51.1	92.7	138.9	187.9	243.5	274.6	309.2	347.6
V	0.3	3.9	15.3	37.1	69.4	112.8	170.5	206.0	247.4	295.5
VI		0.8	4.6	14.8	34.7	67.6	119.3	154.5	197.9	251.1
VII		0.2	1.4	5.9	17.4	40.6	83.5	115.9	158.3	213.5
VIII			0.4	2.4	8.7	24.4	58.5	86.9	126.7	181.4
IX			0.1	0.9	4.3	14.6	40.9	65.2	101.3	154.2
X				0.2	1.1	4.4	16.4	32.6	60.8	108.9
XI					0.3	1.3	6.5	16.3	36.5	75.6
XII					0.1	0.4	2.6	8.1	21.9	52.9
XIII						0.1	1.0	4.1	13.1	37.0
XIV							0.4	2.0	7.9	25.9
XV							0.2	1.0	4.7	18.1
XVI							0.1	0.5	2.8	12.7
XVII								0.3	1.7	8.9
XVIII								0.1	1.0	6.2
Over XVIII									1.3	14.1
Total	3451.1	3053.7	2704.2	2412.9	2219.2	2160.3	2298.3	2473.6	2766.3	3258.6
Growth factor	1.67	1.59	1.47	1.31	1.10	0.85	0.59	0.46	0.35	0.23

$$2000 = r_1gw_1 + sr_1gw_2 + s^2r_1gw_3 \ldots + s^{n-1}r_1gw_n$$

where $r_1 = \frac{r + 1000}{2}$, since 1000 was established as "normal" recruitment

and g is the factor by which the growth is to be multiplied.

If the basic natural mortality rate is adjusted so that the natural mortality rate is increased as the standing crop increases above the carrying capacity, the effect will be that a smaller proportion of the total mortality will be fishing mortality. The fishing mortality with various total mortalities and adjusted natural mortalities can be computed as follows (Table 4):

$$a = jn + m - mjn$$

where j = factor for adjusting natural mortality rate.

The percentage of the population which will then be caught each year can be determined as follows:

$$\text{Percentage caught} = \frac{m}{m + jn} \cdot a$$

Table 4. Fishing mortality rates at various total mortality rates with the natural mortality rates adjusted so that the effect on the mortality rate is one-half of that on growth in Table 3.

Natural mortality	Fishing mortality at various total mortalities								
	90%	80%	70%	60%	50%	40%	30%	25%	20%
15	88.89	77.67	66.11	54.19	41.35	28.46	14.56	7.43	0.06
20	88.47	76.77	64.58	51.87	38.27	23.57	7.77		
25	88.01	75.79	62.56	49.25	34.43	17.95			
30	87.51	74.73	61.06	46.42	31.03	11.43			
40	86.38	72.30	56.77	39.58	19.35				
50	85.02	69.35	51.42	30.74	4.76				
60	83.36	65.69	44.55	18.86					
Growth adjustment factor	1.67	1.59	1.47	1.31	1.10	0.85	0.59	0.47	0.34
Mortality adjustment factor, j	.665	.695	.765	.845	.95	1.075	1.205	1.265	1.33

The catch can then be estimated for various levels of mortality (Table 5, Figs. 3 and 4). As the fishing pressure increases, the number of fish caught increases (Fig. 3), but the increases in numbers do not level off as they do according to Model A (Fig. 1). The total poundage in the catch also increased steadily and did not show the maximum catch followed by a decline which Model A showed (Fig. 2).

Table 5. Numbers (N) and pounds (P) of fish caught with various basic natural (15 per cent and 50 per cent as examples) and fishing (M) mortalities from population under conditions of Table 3 and with natural mortality adjusted as per Table 4.

15 per cent			50 per cent		
M	N	P	M	N	P
0.06	2	2	4.8	101	91
7.4	182	141	30.7	610	505
14.6	309	269	51.4	1085	803
28.5	552	511	69.4	1627	1066
41.4	897	744	85.0	2233	1294
54.2	1173	973			
66.1	1613	1193			
77.7	2154	1411			
88.9	2793	1618			

Model C, by recognizing the carrying capacity concept and the compensations in growth, recruitment, and mortality as the population varies from the carrying capacity, is probably more realistic than Model A. However, it was necessary to arbitrarily set the degree to which growth, recruitment, and mortality are modified to compensate for deviations from the carrying capacity. Studies should be undertaken to determine how much each is modified. Model C assumes that the compensating ability is sufficient to bring the population to carrying capacity in a very short time, regardless of the rate of removal.

MODEL E

It is unlikely that growth, recruitment, and natural mortality can be modified as drastically as is indicated in Model C for the higher total mortalities. It was assumed that the growth could be 1.67 times the present average for the 90 per cent mortality example. This supposes that there would be much faster growing walleyes than has yet been reported in the literature. For Model E let us therefore assume that the growth cannot be more than 1.4 times the present average.

There is also a minimum beyond which the basic natural mortality cannot fall. Let us assume that 15 per cent is the minimum. Likely the

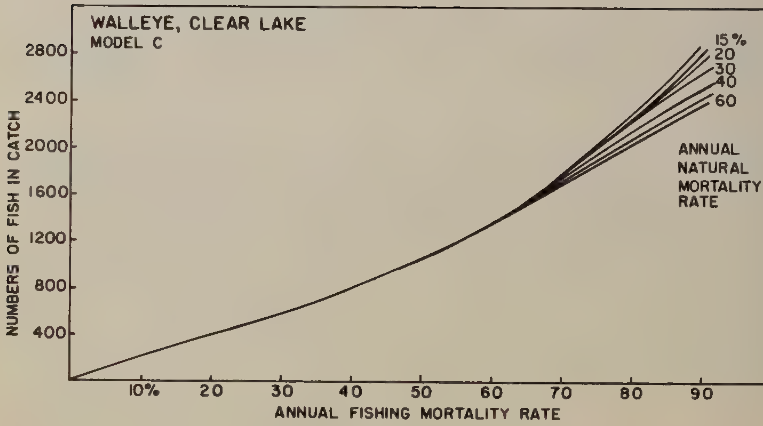

Fig. 3. Number of walleyes caught with different annual fishing mortality rates and with annual natural mortality rates of 15 to 60 per cent, according to conditions of Model C

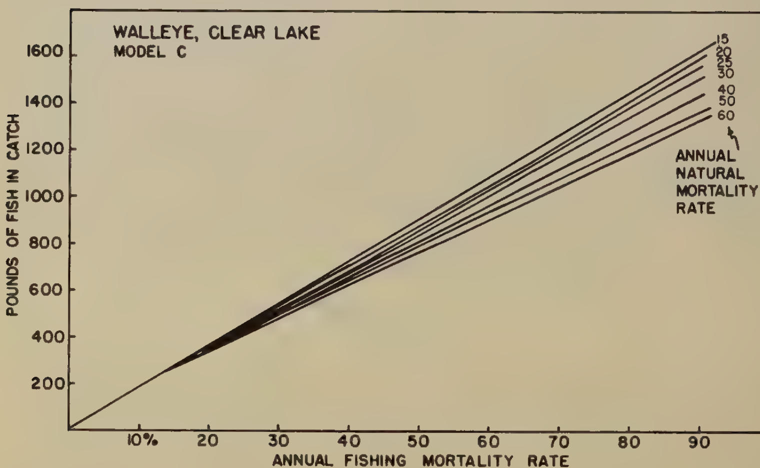

Fig. 4. Pounds of walleyes caught with different annual fishing mortality rates and with annual natural mortality rates of 15 to 60 per cent, according to conditions of Model C

minimum would be somewhat higher. Since this is the basic mortality, the actual annual mortality might be somewhat less. Let us assume that survival from egg to age I cannot be more than 99 per cent.

These limitations have very little effect on the computed catch and the adjustments must be much more limited if the catch is to be noticeably affected.

MODEL F

Models C and E assume that recruitment, growth, and natural mortality will be constant for each given situation. Of course, in a natural situation these characteristics will vary but on the average will give the results indicated. Let us now consider a situation in which recruitment completely fails during some of the years.

Lack of recruitment would reduce the standing crop which would, according to our model, increase the growth rate and decrease the natural mortality of the remaining fish providing these were not already at their limits (using the limits of Model E). The effect of a single failure in recruitment or of various combinations of failures can be computed in a fashion similar to the examples in Tables 6 and 7. These computations were time consuming and required constant attention to detail, but there is nothing in them that involves difficult mathematics. It is quite instructive to try a number of such situations to see the ways in which a fish population may adjust.

In the model which follows I have used only consecutive failures and have neglected the additional losses which would result from the pairing of failures with one, two, or more years between the pair. I did try one series, with 90 per cent total mortality, given below, which indicated that the additional losses tend to be quite variable and may average out:

Losses in numbers (and pounds in parenthesis) with the failures of recruitment (F) separated by the indicated number of years.

F	4,800 (2319)
F + 1 + F	12,208 (5903)
F + 2 + F	6,442 (3113)
F + 3 + F	11,444 (5532)
F + F	14,755 (7134)

The two failures with two years between them had less effect than if the two failures had been independent of each other. The effect of each failure is a function of the population structure at that time. In general, however, it is expected that the association of failures with each other will increase the losses over those of separated failures. Since only the consecutive failures are considered in the present model, it is likely that the losses are somewhat underestimated.

As an aid in computing the effects of recruitment failure on the catches under different fishing and natural mortalities, the losses in numbers and pounds were converted to percentages of the standing crop.

Table 6. Computations to determine the effect of a missed year of recruitment with 90 per cent total mortality, growth already at a maximum.

Age class	Age class composition at each succeeding year									
	1	F	F + 1	F + 2	F + 3	F + 4	F + 5	F + 6	F + 7	Loss
I	3721.0	-	4581.0	3688.0	1895.4	4142.0	3704.0	3717.0	3721.0	
II	372.1	372.1	-	458.1	368.8	189.5	414.2	370.4	371.7	
III	37.2	37.2	37.2	-	45.8	36.9	19.0	41.4	37.0	
IV	3.7	3.7	3.7	3.7	-	4.6	0.5	1.9	4.1	
Total	4134.4	413.4	4622.3	4150.2	2310.4	4373.0	4141.4	4131.1	4134.0	4800.0
Weight	2000.0	442.2	2000.0	1999.8	1238.5	2000.0	2000.2	2000.0	1999.9	2319.0
Egg production		550,384	490,848	189,540	537,150	525,367	378,080	544,094	550,574	

Table 7. Part of computations to determine losses due to two consecutive failures in reproduction with 25 per cent total mortality, showing adjustment of growth to compensate for reproductive failure.

Age group	Mean weight in pounds	Average increment	Sum of increments from oldest up	Age class composition at various years (mean weight in parentheses)			
				1	F*	2F	2F + 1
I	0.138	0.138		651.0			2308.9 (0.138)
II	0.319	0.181	494.60572	488.3	488.3 (0.3519)		
III	0.6181	0.2991	406.22342	366.2	366.2 (0.6724)	366.2 (0.7765)	
IV	0.8999	0.2818	296.69300	274.6	274.6 (0.9511)	274.6 (1.0734)	274.6 (1.0583)
V	1.2966	0.3967	219.31072	206.0	206.0 (1.3686)	206.0 (1.5156)	206.0 (1.4701)
VI	1.5266	0.2300	137.59052	154.5	154.5 (1.5683)	154.5 (1.6959)	154.5 (1.7456)
VII	1.8688	0.3422	102.05552	115.9	115.9 (1.9309)	115.9 (2.0553)	115.9 (2.0381)
VIII	2.1563	0.2875	62.39454	86.9	86.9 (2.2085)	86.9 (2.3400)	86.9 (2.3428)
IX	2.4438	0.2875	37.41948	65.2	65.2 (2.4960)	65.2 (2.6176)	65.2 (2.6275)
X	2.7313	0.2875	18.68100	32.6	32.6 (2.78351)	32.6 (2.9051)	32.6 (2.9042)
XI	3.0188	0.2875	9.31176	16.3	16.3 (3.0709)	16.3 (3.1926)	16.3 (3.1926)
XII	3.3063	0.2875	4.62714	8.1	8.1 (3.3584)	8.1 (3.4801)	8.1 (3.4801)
XIII	3.5938	0.2875	2.29920	4.1	4.1 (3.6459)	4.1 (3.7676)	4.1 (3.7676)
XIV	3.8813	0.2875	1.12086	2.0	2.0 (3.9334)	2.0 (4.0551)	2.0 (4.0551)
XV	4.1688	0.2875	0.54606	1.0	1.0 (4.2209)	1.0 (4.3326)	1.0 (4.3326)
XVI	4.4563	0.2875	0.25866	0.5	0.5 (4.5084)	0.5 (4.6301)	0.5 (4.6301)
XVII	4.7438	0.2875	0.11496	0.3	0.3 (4.7959)	0.3 (4.9176)	0.3 (4.9176)
XVIII	5.0313	0.2875	0.02875	0.1	0.1 (5.0834)	0.1 (5.2051)	0.1 (5.2051)
Total				2473.6	1822.6	1334.3	3277.0
Weight				2000.0	2000.0	2000.0	2000.0

*Growth was determined by determining the weight needed to bring standing crop to 2000 pounds (e.g., 651.0 times 0.138 = 89.8 pounds) and dividing this by the sum of the increments (494.60572) to give the added percentage increment needed (18.156 per cent). Since 118.156 times the increment does not give growth above the allowable maximum, the population has made full adjustment for the lost recruitment.

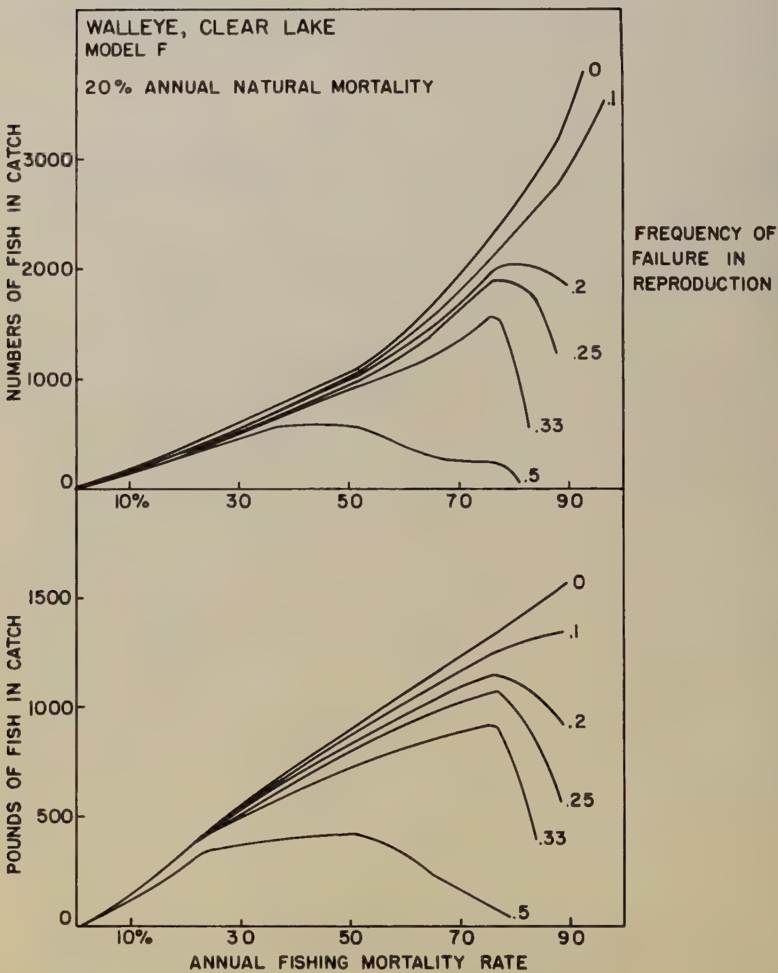

Fig. 5. Numbers and pounds of walleyes caught with different annual fishing mortality rates, with 20 per cent annual natural mortality, and with failure of reproduction once in 2, 3, 4, 5 and 10 years compared with that where there are no reproductive failures and with other conditions as in Model C.

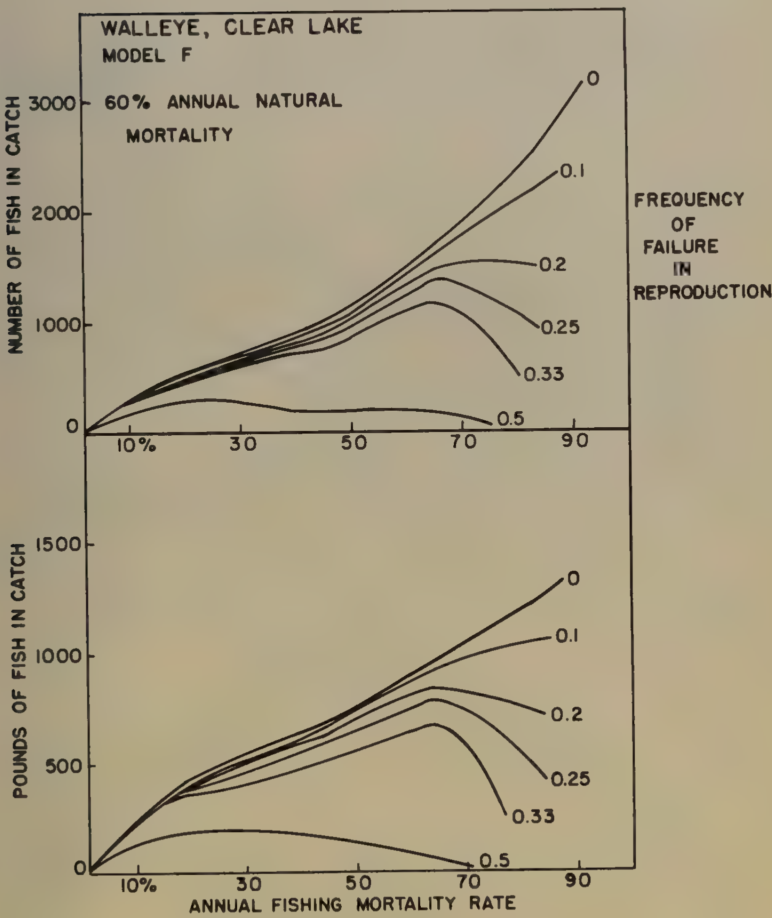

Fig. 6. Numbers and pounds of walleyes caught with different annual fishing mortality rates, with 60 per cent annual mortality, and with failure of reproduction once in 2, 3, 4, 5, and 10 years compared with that where there are no reproductive failures and with other conditions as in Model C

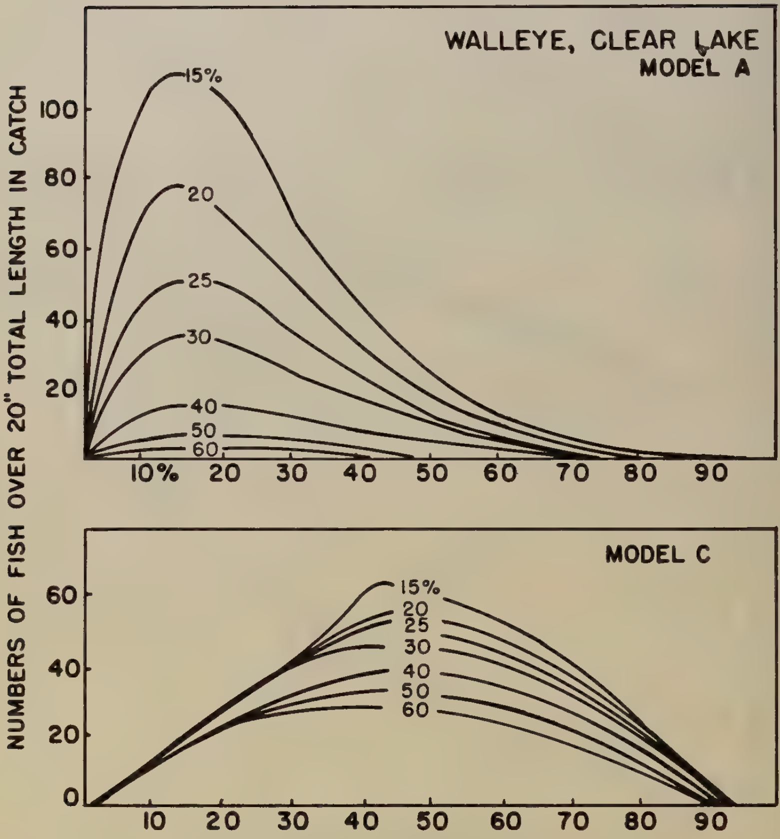

Fig. 7. Numbers of walleyes over 20 inches, total length, caught with different annual fishing mortality rates and with annual mortality rates of 15 to 60 per cent, according to conditions of Model A and of Model C

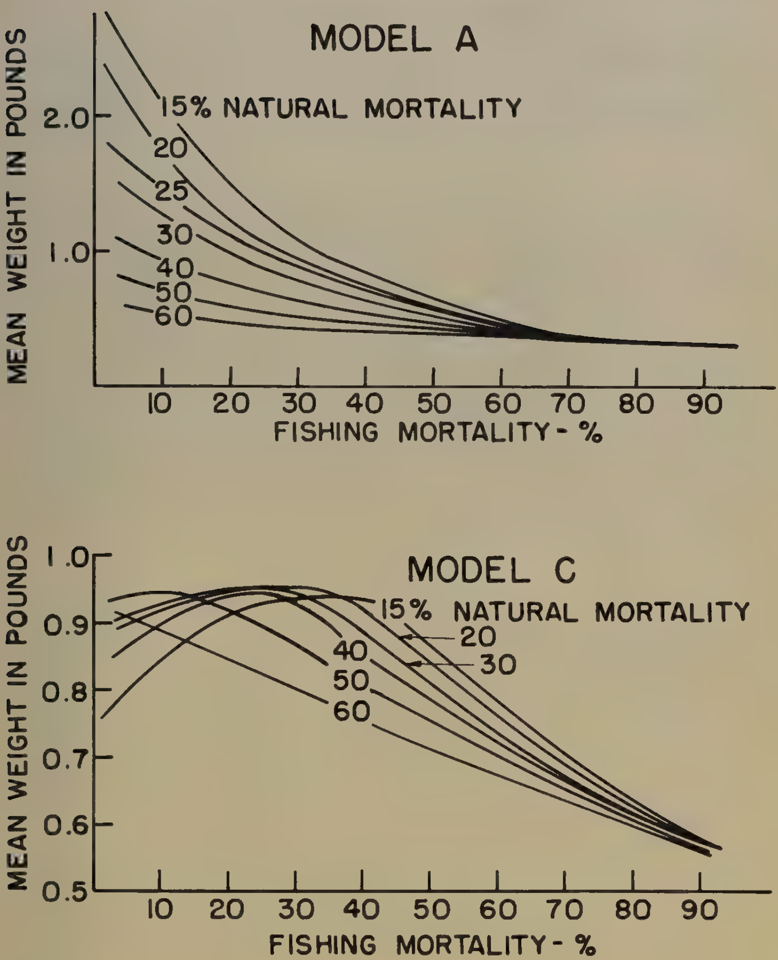

Fig. 8. Mean weight of walleyes in pounds, caught with different annual fishing mortality rates and with annual natural mortality rates of 15 to 60 per cent, according to conditions of Model A and of Model C

If it is assumed that on the average there will be a recruitment failure one in ten years, the total percentage loss can be computed as

0.1 times the percentage loss for one failure

plus 0.01 times the additional percentage loss for paired failure

plus 0.001 times the additional percentage loss for failure three times in a row

etc.

With 90 per cent total mortality, the population will be lost through lack of brood stock (considering 0.1 of a fish from the original recruitment as the minimum brood stock) if there are 5 consecutive failures; with 80 per cent total mortality, the brood stock will be gone if there are 7 consecutive failures.

Even a failure in recruitment once in three years is taken in stride, at least up to 50 per cent fishing pressure (Figs. 6 and 7). Failure of recruitment half of the years results in lower catches and is beyond the capability of the populations in this model to compensate adequately. It is interesting that even with failure of recruitment half of the years, the catch increases until the fishing mortality is at about the 50 per cent level. In all of the models there would seem to be little danger in increasing fishing pressure up to this level.

LARGE FISH

Anglers are often less concerned about the number of fish they catch, or even the poundage, than the number of large fish they catch. From the size distributions in the various age classes, the numbers of walleyes over 20 inches (2.75 pounds) in the catch were estimated for Models A and C (Fig. 7). The maximum number of large fish are caught with fishing rates of about 15 to 20 per cent with Model A but with rates of 40 to 50 per cent with Models C-F. It has already been pointed out that the accumulations of large old fish such as are secured with Model A at low mortality rates are unrealistic.

Although the greatest numbers of large fish are taken, in Model C, with 40 to 50 per cent fishing pressures, the proportion of the catch that is composed of these large fish is greater at lower fishing intensities. In other words, the probability of a person catching one of these fish decreases with the increased fishing pressure before the maximum number is caught. With Model C the maximum proportion of walleyes over 20 inches is about 72 in a thousand. With a natural mortality of 15 per cent, this maximum proportion is attained with a fishing mortality 28–30 per cent, with

natural mortality of 20%	a fishing mortality of 23–25%
25%	18–20%
30%	11–13%
50%	4%

AVERAGE SIZES

The average sizes of the walleyes in the catch may also be estimated for Models A and C (Fig. 8). In Model A the average size drops rather rapidly with increasing fishing pressure as long as natural mortality rates are low. In Model C the average size with low mortality rates is not at the maximum because of the slower growth rate, when populations are allowed to accumulate. The maximum average size of the walleyes in the catch is found when

fishing mortality is about 41%	if natural mortality is 15%
38%	20%
34%	25%
31%	30%
19%	40%
5%	50%

These average sizes are based upon the assumption that all walleyes over 1 year old are caught in proportion to their abundance. In actual practice fishermen catch a greater proportion of the middle-sized and large walleyes than they do small ones because the tackle used is selective for these sizes. Furthermore, the small fish may be thrown back if there is a possibility of catching larger ones. The average sizes caught would, therefore, be somewhat larger, particularly at the lower mortality rates.

BROOD STOCK

In Models E and F it was assumed that recruitment could not be more than 1 per cent of the egg production. Nothing has been said as yet in Models A and C about the dangers of depleting the brood stock to the degree that there will not be sufficient recruitment. From the available data on the number of eggs produced by female walleyes at various sizes (Eschmeyer, 1950), we can estimate the egg production at the various resulting population levels and determine the percentage survival needed from these eggs to provide the needed recruitment at Age I (Table 8). A survival of 1 to 3 per cent to Age I would not seem improbable based upon salmon studies, but little information on survival of walleyes for this period of life is available. In any event it would seem that brood stock would be a limiting factor only at the highest annual mortality rates. As the brood stock becomes rare, the egg survival might show a marked decline due to failure of proper fertilization.

CATCH PER EFFORT

The number of fish caught per hour is a measure of fishing success that is of considerable importance to the angler. Many factors affect fishing success but over a period of time, fishing success is probably positively correlated with the numbers of available catchable-sized fish.

Table 8. Percentage survival needed from egg to age I, at different total annual mortality rates, with Models A and C

Model A		Model C	
Mortality rate (%)	Percentage survival needed	Mortality rate (%)	Percentage survival needed
19.25	.0008	15	.0015
27.75	.0017	20	.0024
36.25	.0036	25	.0031
41.5	.0059	30	.0034
49.0	.012	40	.0041
57.5	.026	50	.0079
66.0	.063	60	.018
74.5	.16	70	.045
83.6	.56	80	.135
91.5	2.8	90	.68

Let us assume that the catch per hour is directly proportional to the average number of catchable fish during the year, disregarding the recruitment during the year and that one fish per hour is equivalent to an average population of 2000 fish. With Model A the catch per hour is much higher at low mortality rates due to accumulations of fish (which are probably unrealistic) (Fig. 9). With Model C at the lowest mortality rates the catch per hour is somewhat higher than at other mortality rates but otherwise the catch per hour seems little affected by the fishing or natural mortality rates. In Model C recruitment and growth compensate for more rapid removal. The lowest catch per hour with Model C is with fishing rates of 20 to 60 per cent, and the fishing success rises slightly with heavier fishing pressure. Since fishing success probably would show a decline with very heavy fishing pressure, the compensations assumed for Model C are probably somewhat greater than take place in nature.

DISCUSSION

It has been pointed out that Model A is similar to those proposed by Baranoff (1918) and by Thompson and Bell (1934). Baranoff assumed that the growth rate was constant and that the weight increased as the cube of the length. Thompson and Bell assumed that the growth rate was 21 per cent per year. The use of the observed growth data in Model A eliminates the errors of assumed constant growth which affect Baranoff and Thompson and Bell models. The Beverton and Holt model (Beverton, 1954) computes the growth according to the Bertalanffy equation which is fitted to the actual growth data and takes into account the fact that growth

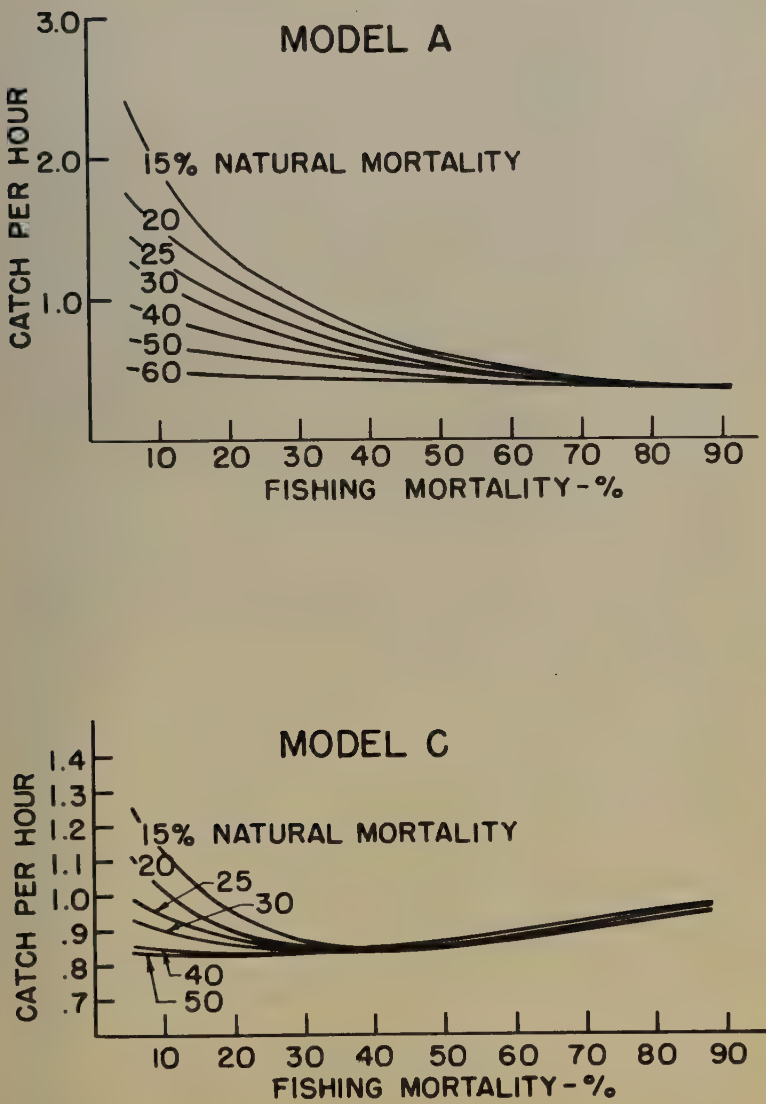

Fig. 9. Expected catch per hour of walleyes at different annual fishing mortality rates with annual natural mortality rates of 15 to 60 per cent, according to conditions of Model A and of Model C, if catch per effort is proportional to abundance of catchable fish.

is not constant throughout life. The effects that the use of a constant growth rate instead of an empirical sigmoid curve would have on the estimation of sustained yields in various models have been discussed by Tester (1953). The Beverton and Holt model also takes into account the fact that the fish do not come into catchable size abruptly but that recruitment to catchable size is a gradual process.

Comparison of the models in the present paper with the above mentioned models shows rather clearly come of the advantages of the mathematical models using calculus over the simple computations used in the present paper. In the present paper it has been necessary to make the computations at arbitrary units of mortality and to interpolate from the graphs for intermediate points. Furthermore, it has been necessary to assume that recruitment takes place at the beginning of each season, that annual growth takes place at one instant, and that the fishing and natural mortality rates are proportional throughout the season. The advantages of the instantaneous growth and mortality rates which are used in most models have been discussed by Ricker (1944, 1948).

Model C, however, makes adjustments for carrying capacity and the resulting effects on growth, recruitment, and natural mortality which are not yet incorporated into any of the more mathematically advanced models. Model C is developed with an arbitrary set of compensations. The magnitude of the yields and the points at which optimum yields can be attained may vary considerably if different sets of compensations are tried. These compensations in nature may be of very different magnitude. Efforts must therefore be made to measure these compensations. Watt (1955), in studies on Tribolium confusum populations, develops a model which takes some of these interactions into consideration. He also discusses the application of this model to fishery populations, pointing out the significance of the type of harvest and of the residual population to yield estimates. Watt (1956) discussed the difficulties in securing data for the application of mathematical models in fisheries. Ricker (1954) discusses the adjustments of recruitment which may be expected with different levels of brood stock.

Experimentation with models such as those described in the present paper is recommended for biologists without sufficient mathematical background to adequately understand the models using calculus. Obviously fish populations do not follow mathematical formulations such as have been proposed, but these computations give a better understanding of some of the possible population changes and suggest the magnitude of change in fishing pressure or other factors which might be expected to bring about an observable change in the fish population or the catch.

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THE PLANKTON OF NORTH TWIN LAKE, WITH PARTICULAR REFERENCE TO THE SUMMER OF 1955[1]

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INTRODUCTION

North Twin Lake is a shallow prairie lake in the north central portion of agriculturally-rich Calhoun County, Iowa. In 1939 and 1940 the lake was dredged by the Iowa State Conservation Commission to increase its recreational values. When the water flows over the barrier at the outlet into South Twin Lake, the 135 acre dredged portion of the lake is now 13 to 15 feet deep while the undredged northern portion has a maximum depth of 6 to 8 feet. The lake is approximately 2.5 miles long, northeast-southwest, and has a maximum area of 569 acres. During recent drought years the water level has fallen almost 3 feet below the outlet.

Higher aquatic vegetation both submersed and emergent is noticeably sparse and exhibits a somewhat spotty distribution in North Twin Lake. Emergent vegetation is present only in small amounts and in scattered locations around the lake proper. Only three forms were found to be prevalent. They included the cattail, Typha latifolia L.; the soft-stem bulrush, Scirpus validus Vahl.; and the river bulrush, Scirpus fluviatilis (Torr.) Gray. Potamogeton filiformis Pers. was the only submersed form detected and it occurred sparsely at several locations. Its annual development in most years appeared to follow a pattern of relatively luxuriant growth during the spring and early summer months followed by a rapid deterioration probably caused by progressive increases in water turbidity.

Attached filamentous algae occasionally attained good development in the shallows at the water's edge. The principal forms here were species of Cladophora and Stigeoclonium.

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North Twin Lake is quite shallow and is subjected to almost continual wind activity, since the surrounding countryside provides little shelter. As a result, definite permanent thermal stratification does not exist during the summer months. Temporary stratifications undoubtedly develop from time to time but none was ever detected.

Dissolved oxygen was always found to be adequate at all depths during the summer months (excluding the possibility of its depletion in the zone immediate to the mud-water interface in the deeper portions of the lake). Indications are that it is in plentiful supply at other periods also except during an occasional winter when an abnormally thick and persistent ice-snow cover in conjunction with a low water level may permit oxygen depletion and resultant winterkill of fishes. The water of North Twin Lake is alkaline in reaction, and, depending on various factors, the pH ranges from about 7.6 to 8.4. Ebullition of methane and possibly other gasses is a common occurrence in the areas of deep water at the south end of the lake. Surface temperatures that approached 85°F have been recorded during exceptionally hot summers (e.g., 1955). Bottom temperatures were always found to be within a few degrees of the surface temperatures. The foregoing and other characteristics place North Twin Lake in the Temperate Lake - Order 3 category of Forel's and Whipple's system of lake classification and clearly establish it as eutrophic in accordance with Welch (1952).

METHODS

The plankton organisms from 59 samples collected from 1951 to 1956 (Table 1) were identified. The 1951 to 1954 samples were collected by filtering measured quantities of surface water through a plankton net.

Table 1. Summary of water samples for plankton analysis taken from North Twin Lake, Iowa, during the years 1951-56

Year	Number of samples	Dates collected (Numbers of samples in parentheses)
1951	4*	July 23; August 13; October 6
1952	3*	July 12; 18; 31
1953	1*	September 1
1954	11*	July 7; 19(3); 20; August 2(2); 3; 16(2); 18
1955	37**	June 9; 10; 24(2); July 8; 9; August 2(3); 4; August 15(4); 16; 17; 20(2); 29(2); 30(3); September 12(2); 14(2); 16; 22; 23; October 6(3); 7; 21 (3)
1956	3**	March 27; April 15; June 9
Total	59	

*Net samples.
**Centrifuged samples.

The 1955 and 1956 samples were 2-liter samples taken with a Kemmerer sampler at 6 inches below the surface or by submerging a 2.5-liter bottle 6 inches below the surface and allowing it to fill to the 2-liter mark. The plankton in each 2-liter sample was concentrated to about 15 milliliters by means of a Foerst continuous flow centrifuge (1955 model: about 20,000 rpm). The rate of centrifuging was standardized at about one liter per eight minutes. The general procedure was to centrifuge each sample immediately following its removal from the lake and prior to fixation. Very satisfactory fixation was obtained for practically all plankton forms by flooding the concentrate with a very hot 10 per cent formalin solution. Even better results in the fixation of certain zooplankters were obtained later in the study by narcotizing these forms with menthol prior to their fixation with formalin.

The over-all advantages of using the centrifuge method for concentrating plankton samples became quite apparent as the study progressed. The nannoplankton[1] components which probably constitute the bulk of the plankton standing crops of most waters were sampled much more efficiently by this method than they could have been with the usual plankton net.

Most phytoplankton forms occurring in North Twin Lake fall into this category at some time during their life cycle. Many of the Chlorococcales, for example, some Crucigenia, most Oocystis, Schroederia, and Tetrastrum are nannoplanktonic at all stages of development. Others such as Coelastrum are not necessarily nannoplanktonic when mature but may produce at certain periods large numbers of autocolonies which do fall into this category. Hence net samples containing Coelastrum obtained during periods when autospore formation is at a peak would theoretically contain only the largest individuals, resulting in misleading information relative to its abundance. Other important nannoplankton forms not ordinarily captured with the net but easily sampled using the centrifuge method include many diatoms, various protozoans such as minute rhizopods and ciliates, and the minute and abundant colonies of certain blue-green algae.

Several disadvantages are reportedly inherent in the centrifuge method of plankton concentration. It is felt, however, that they are far outweighed by the method's advantages. One purported disadvantage is that the centrifuge is inefficient in concentrating those blue-green algae possessing a very low specific gravity. (Forms containing pseudovacuoles such as Microcystis and Aphanizomenon fall into this category.) However, frequent checks of centrifuged water consistently indicated little or no loss of any plankton forms. Several double centrifugations also

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[1]Naumann (1931) designates nannoplankters as those components of the bioseston whose greatest dimension lies between 5 and 60 microns and which can be separated from the water only by sedimentation or centrifugation. Welch (1952) defines nannoplankton as that portion of the plankton which readily passes through number 25 silk bolting cloth (mesh size from .030 to .040 mm). In her study, Ballentine (1953) included small flagellates of less than one micron in length in the nannoplankton. Rodhe (1955) terms these minute and usually overlooked forms the "μ" plankton.

indicated that no residual material remained following initial centrifugings. It might be well to point out, however, that blue-green blooms were not noticeably present in North Twin Lake during the 1955 summer. Perhaps in the presence of excessive amounts of such forms, the centrifuge may lose some of its efficiency in their retention.

Another purported but not necessarily unique disadvantage of the centrifuge method lies in the loss of varying amounts of plankton due to their adhesion to the glassware, etc. used in this method. Errors from such sources are inherent in almost any method. In any event, it is suggested that such errors need not be significant if the proper precautions (such as the use of consistently clean glassware) are taken.

A real disadvantage of the centrifuge method is that all components of the plankton, even finely divided organic and inorganic detritus, are included in the concentrate. The presence of large amounts of detritus often becomes a problem during enumeration since many of the organisms being counted become obscured. By properly diluting the concentrate and occasionally adding a bit of weak detergent solution to break up the concentrate clumps, the presence of large amounts of debris presented no serious problems during the study.

A standard Sedgwick-Rafter counting cell was used in making counts of the plankton organisms and the procedures followed those recommended by the American Public Health Association (1946).

Prior to actual counting, the raw plankton concentrate was diluted to the desired degree and then thoroughly mixed by vigorous agitation. While still agitating the concentrate, a one milliliter portion was withdrawn with a large-bore pipette and introduced into the Sedgwidk-Rafter cell. A cover slip which had been lying diagonally across the cell was allowed to move into place during the operation. After permitting the concentrate to settle, enumeration proceeded.

Two magnifications were employed in making the counts, namely, 210X (combination of 10X ocular and 21X (8 mm) objective) and 100X (combination of 10X ocular and 10X (17 mm) objective). The former magnification was successfully used for enumerating all phytoplankton (except occasional large filamentous forms) and protozoans. The latter magnification was used for counting all larger zooplankton such as rotifers and plankton Crustacea. A Whipple ocular micrometer was employed at all times to delimit the "fields" (to be counted) within the Sedgwick-Rafter cell. The microscope used possessed a draw tube which, with the aid of a stage micrometer, permitted calibration of the ocular micrometer so that it covered an area on the bottom of the Sedgwick-Rafter cell of exactly one square millimeter at 100X magnification and an area of exactly 0.25 square millimeter at 210X magnification. In accordance with the findings of Littleford et al. (1940) it was decided that at 210X magnification, counts of organisms in 20 fields selected at "random" from a single one-milliliter concentrate sample would yield fairly reliable estimates of the numbers of each plankton species present in the original lake sample. Counts of the larger zooplankton made at 100X magnification were obtained by examining the entire contents of three successive one-milliliter concentrate samples. The latter technique is called the "survey" method by Welch (1948) and

is used where it is desired to reduce the variability in counts of large, easily identified organisms that are present in small numbers. Factors or multipliers such as described by the American Public Health Association (1946) were computed for each plankton sample analyzed.

An evaluation of the techniques employed in securing numerical and volumetric plankton estimates and measures of their precision is being published in another paper (Kutkuhn, 1958). Plankton volumes were estimated by the "calculated volume" method described by the American Public Health Association (1946) and Welch (1948).

Throughout the study, every effort was made to identify all forms encountered to species if possible. The use of 210 X magnification greatly facilitated identification and counting of even very small forms. It should be pointed out, however, that all plankton forms were carefully identified and studied at higher magnification (if necessary) prior to counting. Occasional doubtful forms encountered during enumeration could often be positively identified while still in the counting cell through judicious use of the 43X (4 mm) objective.

The fact that it is impossible to detect all forms present in fixed samples even at high magnifications was demonstrated when portions of plankton concentrates were stained with a nuclear stain (Delafield's haematoxylin). Numerous small protozoans and motile stages of certain phytoplankton species were found to be present. Obviously, problems arising from an inability to detect many forms are difficult to cope with in studies where complete enumeration of all forms is an objective. Furthermore, as Ballentine (1953) points out, still other forms are completely destroyed when subjected to ordinary fixation. Hence the proper examination of many nannoplankters hinges upon the development of better fixatives and more refined techniques.

The species lists which follow are annotated to give some idea of each species' relative abundance during the study period. Adjectives such as common and uncommon are used to indicate the frequency with which the various forms appeared in the samples and may or may not be validly descriptive of how these forms were actually distributed throughout the lake. In addition, the lists are supplemented by the inclusion of forms encountered only when analyzing fish digestive tract contents. Certain of these forms are not truly planktonic and may only on rare occasions be tychoplanktonic. They are included mainly to add to the completeness of the floral and faunal listings.

The gizzard shad, Dorosoma cepedianum, was very abundant in North Twin Lake in 1954 and 1955 and these plankton studies were made, to a considerable extent, in an attempt to determine the ecological relationships of this fish. All plankton species encountered during shad digestive tract analyses are denoted with an asterisk (*). It will be noted as the lists are reviewed that shad include a remarkably large number of plankton forms in their diet. Such a characteristic has led Tiffany (1921, p. 115) to remark that "... the gizzard shad is about the most wonderful tow net that one could desire to get an estimate of the kinds and proportionate numbers of microscopic algae present in a body of water."

The 1955 numerical estimates for each species are summarized in the annotated list. These counts represent the numbers of individual organisms per milliliter of water.

Although most samples were taken from the littoral areas of the lake, it is believed that the species lists are reasonably complete as regards the plankton populations of the entire lake. Those samples obtained from limnetic situations usually contained, for the most part, the same forms encountered in the littoral samples.

The Phytoplankton

All phytoplankton forms were identified by the author. However, special thanks are due Dr. J.D. Dodd, Department of Botany, Iowa State College and Dr. G.W. Prescott, Department of Botany and Plant Pathology, Michigan State University, for confirming determinations of certain algae.

The classification of the phytoplankton exclusive of the Bacillariophyceae (diatoms) and Desmidiaceae (desmids) is that given by Prescott (1951). Practically all genera and most species and varieties of the Cyanophyta, Chlorophyta, and Mastigophora (Phytomastigophorea) were identified using Prescott's (1951) keys and descriptions. Other important works were referred to where necessary. Thus certain species of the Cyanophyta were identified using the keys and descriptions of Geitler (1925, 1932) and Huber-Pestalozzi (1938). The latter work was also used to identify several planktonic fungi. With one exception all species of Euglena were determined through the use of keys and descriptions given by Johnson (1944).

To aid in identifying certain diatoms, the sulphuric acid-bichromate method described by Hohn (1951) for cleaning diatom frustules proved to be very useful. Most diatom genera were determined with the aid of keys formulated by the same author. Several genera and all diatom species and varieties were identified using the excellent works of Hustedt (1930) and Huber-Pestalozzi (1942).

Determinations of all genera and most species and varieties of the Desmidiaceae were made with the aid of keys and descriptions given by Smith (1924).

In addition to the foregoing, the general works of Smith (1950) and Tiffany and Britton (1952) were of value as supplementary references.

Division CYANOPHYTA

Myxophyceae

Chrococcales:

*Aphanocapsa delicatissima West and West–Very common, especially in midsummer when it may constitute the bulk of the phytoplankton (as, e.g., in 1955). 27-80 (June and July); 4, 325-19, 900 (August to October 6); 306-600 (October 21).

*Aphanocapsa pulchra (Kütz.) Rabenhorst–Common but not nearly as common as A. delicatissima. 0-72 (June-September).

*Aphanocapsa rivularis (Carm.) Rabenhorst–In sample taken in July, 1952. One occurrence in shad digestive tract (1955).

*Aphanothece gelatinosa (Henn.) Lemmermann–One colony found in shad digestive tract (1955).

*Aphanothece nidulans P. Richter–Infrequent occurrences during summer and fall months, occasional in spring. 0-5 (July 9, August 2, September 16).

*Aphanothece saxicola Naegeli–One colony found in shad digestive tract (1955).

*Chrococcus limneticus Lemmermann–Common during summer and fall months. 0-16 (June-July); 15-120 (August); 0-27 (September-October).

Coelosphaerium dubium Grunow–Specimens found in samples taken in July, 1952 and June, 1955. 2 (June 24).

*Coelosphaerium kuetzingianum Naegeli–Uncommon. 0-10 (June-October).

*Coelosphaerium naegelianum Unger–Common in summer, especially in 1951 and 1952. 0-9 (June-September).

Dactylococcopsis fasicularis Lemmermann–Individual cells are quite difficult to distinguish from certain species of Ankistrodesmus (Chlorophyta). Seemingly common in spring.

Dactylococcopsis rhophidioides Hansgrig–Apparently quite common in early spring.

Gomphosphaeria lacustris Chodat–Frequent, especially during late spring and early summer. 0-46 (June 24-August 15); 10-84 (August 16-September 22); 0-6 (September 23-October 21).

Marssoniella elegans Lemmermann–In sample taken in August, 1955. 10 (August 16).

*Merismopedia glauca (Ehrenb.) Naegeli–Common. 5 (September 14).

*Merismopedia tenuissima Lemmermann–Very common during much of the year. 0-15 (June-July); 108-792 (August 2-20); 438-2123 (August 29-September 16); 120-570 (September 22-October 21).

*Microcystis aeruginosa Kütz.–Very common, especially during the summers of 1951, 1952, and 1953. 0-27 (June-October).

*Microcystis incerta Lemmermann–In sample taken in July, 1952. Rare in shad digestive tracts (1955).

*Synechococcus aeruginosus Naegeli–In sample taken in June 1955.

Hormogonales:

*Anabaena circinalis Rabenhorst–Infrequent in plankton samples, common in shad stomachs - June, 1955.

*Anabaena spiroides var. crassa Lemmermann–Very common during early summer. 605 (July 8) otherwise 0-30 (June 24-August 2).

*Anabaena sp.–A form having straight trichomes, very infrequent (1955). (Only specimens with sterile trichomes were found.) 2 (June 9).

*Anabaenopsis circularis (G.S.W.) Wol. and Miller–Fairly common in mid- and late summer (1955). 18-213 (August 15-October 6); 3-9 (October 21) (These counts also include A. elenkini).

*Anabaenopsis elenkini V. Miller–Fairly common, occurring mostly in late summer (1955).

*Aphanizomenon flos-aquae (L.) Ralfs–Common during summer months. 40-160 (June 24-July 9); 0-27 (August 2-October 6).

*Lyngbya aerugineo-caerulea (Kütz.) Gomont–Tychoplankter, no occurrences in plankton samples. In shad digestive tract (1955).

*Lyngbya contorta Lemmermann–Very common during summer months (1955). 1 (June 9); 0 (June 10-August 4); 0-24 (August 15-29); 210-1290 (August 29-October 6); 45-52 (October 21).

Nostoc sp.–Rare in plankton. Occurred twice in samples taken in September, 1955. 0-9 (September 12-16).

*Oscillatoria limnetica Lemmermann–Very common during summer months. 18-360 (August 29-October 21).

Oscillatoria limosa (Roth) C.A. Agardh–One filament in sample taken in April, 1956.

*Oscillatoria prolifica (Grev.) Gomont–Common in shad digestive tracts (June, 1955).

Oscillatoria sp.–In samples taken in April, 1956.

*Phormidium mucicola Naumann and Huber-Pestalozzi–Common in mucilage of Microcystis aeruginosa.

Spirulina nordstedtii Gomont–A single occurrence in September, 1955.

*Spirulina princeps (West and West) G.S. West–One occurrence in August, 1955.

Fungi

(?) Asterothrix raphidioides (Reinsch) Printz–Common in early spring (1956).

*Planctomyces sp.–Very infrequent occurrences in samples taken during the 1955 summer and fall.

*Fungus spores (Unidentified)–Common in the 1955 samples.

Division CHLOROPHYTA

Chlorophyceae

Tetrasporales:

*Gloeocystis gigas (Kütz.) Lagerheim–Common in spring and early summer. 0-28 (June); 0 (July); 13-90 (August 2-20); 0-25 (August 29-October 21) (These counts also include G. major.)

*Gloeocystis major Gerneck ex Lemmermann–Common in spring and early summer.

*Gloeocystis vesiculosa Naegali–One colony collected in October, 1955.

Sphaerocystis schroeteri Chodat–Fairly common in spring and early summer. 4-15 (June); 2 (August 2); 6 (August 15).

Ulotrichales:

*Ulothrix aequalis Kützing–Tychoplankter. Found in shad digestive tracts, (1955).

Chaetophorales:

*Stigeoclonium subsecundum Kützing–Tychoplanktonic. Found only in shad digestive tracts (1955).

Cladophorales:

*Cladophora insignis (C.A.Ag.) Kützing–Tychoplankter. Not encountered in plankton samples. Occurred in shad digestive tract (1955).

*Pithophora oedogonia (Mont.) Wittrock–In shad digestive tract (1955).

Oedogoniales:

*Oedogonium sp.–Found only in shad digestive tracts (1955).

Chlorococcales:

Actinastrum hantzschii Lagerheim–One occurrence in April, 1956.

*Ankistrodesmus falcatus (Corda) Ralfs–Very common during spring, early summer, and fall. 35-240 (June 9-August 4); 0-60 (August 15-October 6); 1683-2019 (October 21) (These counts also include the following two forms).

*Ankistrodesmus falcatus var. mirabilis (West and West)–Common in spring and early summer.

*Ankistrodesmus falcatus var. stipitatus (Chod.) Lemmermann–Fairly common in spring and early summer.

Botryococcus sudesticus Lemmermann–Rare. 5 (August 16); 5 (September 14).

Characium ambiguum Hermann–Epiphytic on Melosira filaments but often found free in plankton concentrates.

Characium gracilipes Lambert–Tychoplanktonic. Very common in spring.

*Coelastrum cambricum Archer–Very common at all periods. 0-18 (June-October).

*Coelastrum microporum Naegeli in A. Braun–Very common at all periods. 2-12 (June-July); 10-113 (August-September 14); 0-12 (September 16-October 21).

*Coelastrum reticulatum (Dang.) Senn–Relatively uncommon in plankton samples (1955). 5 (August 17).

*Crucigenia crucifera (Wolle) Collins–Common during summer months. 6-8 (August 15); 5-36 (August 20-September 23).

*Crucigenia irregularis Wille–Rare. One or two occurrences in 1955.

*Crucigenia quadrata Morren–Very common - the most frequently occurring species of Crucigenia. 0-60 (June-October).

*Dictyosphaerium ehrenbergianum Naegeli–Frequent to common in spring and summer. 0-65 (June 24-October 21) (These counts also include D. pulchellum).

*Dictyosphaerium pulchellum Wood–Common in spring and summer.

*Dimorphococcus lunatus A. Braun–Fairly common in early summer. 1 (June 24).

*Franceia droescheri (Lemm.) G.M. Smith–Frequent occurrences in spring and summer (1955). 0-8 (August 2-20).

*Golenkinia paucispina West and West–Fairly common, occurring with G. radiata. 15-126 (August 2-30); 195-525 (September-October) (These counts also include G. radiata).

*Golenkinia radiata (Chod.) Wille–Common, especially in spring and fall.

*Kirchneriella contorta (Schmidle) Bohlin–Very infrequent in occurrence.

*Kirchneriella lunaris (Kirch.) Möbius–Common throughout the summer and fall months. 0-12 (July 8-August 30); 25-125 (September 12-16); 0-15 (September 22-October 21).

*Kirchneriella obesa (W. West) Schmidle–Fairly common during the summer months. 0-54 (August 2-October 21) (These counts may also include other Kirchneriella spp.).

Kirchneriella subsolitaria G.S. West–Infrequent occurrences during the summer months.

*Lagerheimia ciliata (Lag.) Chodat–Fairly common during spring, summer, and fall months. 0-25 (August 2-August 30) (These counts include other Lagerheimia spp.)

*Lagerheimia citriformis (Snow) G.M. Smith–Frequent occurrences in plankton samples and in shad digestive tracts.

*Lagerheimia longiseta (Lemm.) Printz–Occurring with L. ciliata.

*Lagerheimia quadriseta (Lemm.) G.M. Smith–Common. Occurring with L. ciliata.

Micractinium pusillum Fresenius–Fairly common in late spring and early summer. 2-10 (June-July); 0-16 (August 2).

*Nephrocytium agardhianum Naegeli–Frequent occurrences during late summer. 15 (September 22); 6 (October 6).

*Oocystis borgei Snow–Very common in early summer (1955).

*Oocystis lacustris Chodat–Infrequent occurrences in summer and fall (1955).

*Oocystis parva West and West–Very common in spring and early summer - the most common species of Oocystis. 214-519 (June); 8-102 (July-August 4); 245-354 (August 15-20); 10-63 (August 29-October 21). (These counts include other Oocystis.)

*Oocystis submarina Lagerheim–Very common in early summer.

*Pediastrum biradiatum Meyen–Not encountered in plankton samples but found in shad digestive tracts (1955).

*Pediastrum boryanum (Turp.) Meneghini–Fairly common in all samples. 0-50 (June-September 22).

*Pediastrum duplex Meyen–Very common in all samples. 3-90 (June-October 21) (These counts include the two following forms).

*Pediastrum duplex var. clathratum (A. Braun) Lagerheim–This and the following variety of P. duplex were the most frequently occurring forms of Pediastrum in the North Twin Lake collections.

*Pediastrum duplex var. gracilimum West and West–Occurring with P. d. clathratum.

*Pediastrum simplex (Meyen) Lemmermann–Frequent occurrences in all samples. 0-24 (June 10-October 6) (These counts include the following form).

*Pediastrum simplex var. duodenarium (Bailey) Rabenhorst–Common in most samples.

*Planktosphaeria gelatinosa G.M. Smith–Infrequent to common during spring and summer. 2-5 (June 24-July 8); 5 (August 16).

Quadrigula closteroides (Bohlin) Printz–Apparently rare. Occurred in sample taken in September, 1953.

Quadrigula lacustris (Chod.) G. M. Smith–Sporadically common in spring (1956).

*Scenedesmus abundans (Kirch.) Chodat–Very common. Occurred in all plankton samples. 1-16 (June); 28-729 (July-October 21) (These counts also include S. quadricauda).

*Scenedesmus abundans var. asymmetrica (Schroed.) G. M. Smith–In shad digestive tract (1955).

*Scenedesmus abundans var. longicauda G. M. Smith–Very common. In most samples.

*Scenedesmus acuminatus (Lag.) Chodat–Fairly common in mid-summer, 1955. 0-5 (June-July); 54-468 (August 2-October 21) (These counts also include S. dimorphus).

Scenedesmus arcuatus Lemmermann–Frequent occurrences in 1955 samples.

*Scenedesmus bijuga var. alternans (Reinsch) Hansgirg–Very common during spring, summer, and fall months. 0-4 (June); 5-70 (July-August 17); 0-30 (August 20-October 6); 57-66 (October 21).

*Scenedesmus bijuga var. flexuosus (Lemm.) Collins–Fairly common in early spring, 1955. 3-8 (June-July 8); 6 (August 20).

*Scenedesmus denticulatus Lagerheim–Common in spring and summer. 0-10 (June-September 22); 102-108 (October 21).

*Scenedesmus denticulatus var. ? –This form is apparently a new variety (or species?) and is being currently studied by Dr. G. W. Prescott.

*Scenedesmus dimorphus (Turp.) Kütz.–Very common, occurring in all samples.

*Scenedesmus quadricauda (Turp.) Bréb.–Very common, occurring in all samples.

*Scenedesmus quadricauda var. maximus West and West–Occasional occurrences in plankton samples and in shad digestive tracts (1955).

*Schroederia setigera (Schroed.) Lemmermann–Common to very common throughout the spring and summer, 1955. 44-110 (June-July); 2-32 (August 2-17); 0-27 (August 20-October 21).

*Selanastrum gracile Reinsch–Common during summer months. 0-45 (August 2-30).

Selenastrum westii G. M. Smith–Seemingly quite rare. One or two occurrences in samples taken in 1955.

*Sorastrum spinulosum Naegeli–Rare in plankton samples and in shad digestive tracts (1955).

Tetradesmus smithii Prescott–Frequent occurrences in early summer samples (1955). 20 (August 2); 6 (August 20).

*Tetraëdron caudatum var. longispinum Lemmermann–Very common. 0-15 (July 8-September 23); 48-63 (October 21).

Tetraëdron enorme (Ralfs) Hansgirg–Infrequent occurrences in 1955 samples. 12 (August 29).

Tetraëdron gracile (Reinsch) Hansgirg–Uncommon.

*Tetraëdron hastatum (Reinsch) Hansgirg–Common. 0-36 (August 15-October 21).

*Tetraëdron hastatum var. palatinum (Schmidle) Lemmermann–common.
*Tetraëdron limneticum Borge–Common during summer months. 0-26 (June 9-August 17).
*Tetraëdron minimum (A. Bruan) Hansgirg–Uncommon.
*Tetraëdron muticum var. punctulatum (Reinsch) De Toni–Found in shad digestive tracts, 1955.
*Tetraëdron planctonicum G. M. Smith–Infrequent occurrences in 1955 samples.
*Tetraëdron regulare Kütz.–Very common. The most frequently occurring species of Tetraëdron. 2 (June 10); 8-36 (July 8-September 12); 0-6 September 14-October 21).
*Tetraëdron trigonum (Naeg.) Hansgirg–Uncommon.
*Tetrastrum staurogeniaeforme (Schroeder) Lemmermann–Fairly common in spring and fall (1955). 5 (August 4); 5 (August 29); 0-87 (September 12-October 21).

Zygnematales:
Zygnemataceae:

*Mougeotia sp.–Tychoplanktonic. Frequent in samples taken in fall (1955). 0-1 (September 22-October 21).
*Spirogyra sp.–Tychoplanktonic. Very infrequent in plankton samples, occasionally common in shad digestive tracts (1955). (October 21).

Desmidiaceae:

*Closterium acerosum (Schrank) Ehrenb.–Common in digestive tracts of shad collected in June, 1955.
Closterium gracile var. elongatum W. and G.S. West–Common in plankton sample taken in June, 1956.
*Closterium moniliferum (Bory) Ehrenb.–Common in early summer (1955).
*Closterium spp.–Includes several forms of very rare occurrence (1955).
*Cosmarium cyclicum var. nordstedtianum (Reinsch) W. and G.S. West–Uncommon. 0-5 (June 9-September 12).
*Cosmarium punctulatum var. subpunctulatum (Nords.) Börg.–In shad digestive tracts (1955).
*Cosmarium reniforme (Ralfs) Archer–Fairly common in early summer (1955).
*Staurastrum paradoxum Meyen–Common during the spring, summer, and fall months. (The most common species of Staurastrum).
*Staurastrum spp.–Several forms of rare occurrence in 1955 samples none of which were isolated for identification to species. 3-10 (June 9-August 2); 10-52 (August 4-20); 0-18 (August 29-October 21).

Division CHRYSOPHYTA

Xanthophyceae

Ophiocytium capitatum var. longispinum (Möbius) Lemmermann–One specimen encountered in 1955 samples. 10 (August 29).

Bacillariophyceae

Centrales:

*Cyclotella comta (Ehrenb.) Kütz.–Fairly common in spring and fall. 0-24 (June 9-August 29); 5-96 (August 30-October 21) (Counts include C. meneghiniana).

*Cyclotella meneghiniana Kütz.–Common in spring and fall.

*Melosira ambigua (Grun.) O. Müller–Common in spring and fall.

*Melosira granulata (Ehrenb.) Ralfs–The most common species of Melosira; common to abundant in spring and fall. 36-642 (June 9-October 21) (Counts include M. ambigua).

*Melosira granulata var. angustissima Müller–Very common during the 1952 summer.

Rhizosolenia eriensis H. L. Smith–Seemingly very common in early spring (1956).

*Stephanodiscus astraea (Ehrenb.) Grun.–Very common in spring and fall. 91-860 (June); 12-132 (July-September 12); 0-18 (September 14-October 21) (Counts include S. niagarae).

*Stephanodiscus niagarae Ehrenb.–Very common to extremely abundant in spring. Fairly common in fall.

Pennales:

*Achnanthes spp.–Includes several minute forms of very infrequent occurrence (1955).

Amphipleura pellucida Kütz.–Uncommon. Infrequent occurrences in 1955 samples. 0-9 (June 24-August 30).

*Amphiprora ornata Bailey–Common in spring, early summer, and fall. 2-5 (June); 0-8 (August 2-October 6).

*Amphora ovalis Kütz.–Fairly common in spring (1955, 1956). 0-8 (June 9-August 4); 0-3 (October 21).

*Asterionella formosa Hassall–Very common during mid-spring. 2 (June 9).

*Bacillaria paradoxa Gmel.–In samples taken in September, 1953 and April, 1956.

*Caloneis silicula (Ehrenb.) Cleve–Found in shad digestive tracts (1955).

*Cymatopleura elliptica (Bréb.) W. Smith–Frequent to common in spring and fall. 0-9 (June9-September 16).

*Cymatopleura elliptica fo. spiralis (Chase) Boyer–Occasional occurrences in samples taken during the summers of 1954 and 1955.

*Cymatopleura solea (Bréb.) W. Smith–Common in spring and fall. 12 (October 6).

*Cymbella ehrenbergii Kütz.—Probably the most common species of Cymbella, especially in the spring. 2-35 (June 9-August 16); 0-24 (August 17-October 21) (Counts include other Cymbella spp.).

*Cymbella tumida (Bréb.) Van Heurck—Fairly common in early spring (1956).

*Cymbella turgidula Grun.—One of the more common species of Cymbella (1955).

*Cymbella spp.—Includes several forms of seemingly common occurrence in 1955 samples.

*Epithemia argus Kütz.—Uncommon (1954, 1955).

*Epithemia zebra (Ehrenb.) Kütz.—Common during spring, summer, and fall. 0-5 (June 10-October 21).

*Eunotia lunaris (Ehrenb.) Grun.—In shad digestive tracts only.

*Eunotia pectinalis var. minor (Kütz.) Rabenhorts—In shad digestive tracts.

*Eunotia sp.—Frequent occurrences in 1954 and 1955 samples.

Fragilaria capucina Desmaz.—Encountered only in spring and early summer plankton samples.

Fragilaria construens (Ehrenb.) Grun.—Found in shad digestive tract (1955).

*Fragilaria crotonensis Kitten—Very common in early summer. (The most common of the Fragilaria species). 2-27 (June-July); 0-18 (August 16-October 6).

Fragilaria virescens Ralfs—Occasional occurrence in early spring samples (1956).

*Gomphonema sp.—Uncommon in the plankton. 6 (August 20); 6 (October 6).

*Gyrosigma attentuatum (Kütz.) Cleve—Very common in early spring, common throughout summer months. 2-5 (June-July); 5 (August 17).

*Navicula bicapitellata Hust.—Common throughout the 1955 summer.

*Navicula cryptocephala Kütz.—Common in early spring (1956).

*Navicula cuspidata Kütz.—Very common in early spring (1956). 6 (August 20); 10 (August 29); 45 (September 12).

*Navicula rheinhardtii Grun.—Seemingly quite common during the 1955 summer. 2-73 (June-July); 45-332 (August 2-16); 0-110 (August 17-October 21) (Counts include other Navicula spp.).

*Navicula spp.—Includes several more or less rare forms which were not identified to species.

*Neidium dubium (Ehrenb.) Cleve—In shad digestive tracts (October, 1955).

*Neidium iridis var. ampliata (Ehrenb.) Cleve—Very infrequent in samples taken during the 1955 summer.

*Nitzschia acicularis W. Smith—Relatively common. (Sometimes difficult to distinguish from Synedra acus under low power.)

*Nitzschia sigma (Kütz.) W. Smith—Fairly common in spring and fall (1954, 1955). 2 (June 9); 5 (August 16); 5-10 (September 16-22).

*Nitzschia sigmoidea (Ehrenb.) W. Smith—Common, especially in fall. 1 (June 10); 3 (July 9); 6 (August 30).

*Nitzschia spp.—Includes one or two forms of infrequent occurrence. 1-15 (June-July); 0-36 (August 17-30); 5-25 (September 14-October 21).

*Pinnularia major Kütz.—Common in spring and fall.
*Pinnularia spp.—Includes several occasionally common forms which could not be identified to species because of time limitations. 0-36 (June 9-October 6).
*Rhopalodia gibba (Ehrenb.) O. Mull.—In samples taken in early spring (1956).
*Stauroneis acuta W. Smith—In shad digestive tract (1955).
*Surirella biseriata Bréb.—Common to abundant, especially during spring months. 0-3 (June); 3 (August 2); 6 (October 21).
*Surirella biseriata var. bifrons (Ehrenb.) Hust.—Fairly common in early spring.
*Surirella linearis W. Smith—Common in early spring and fall. 24-36 (October 6-21).
*Surirella tenera Greg.—Common in spring and early summer. 2-8 (June-July); 3 (August 15).
*Surirella spp.—Includes several less common forms of sporadic abundance. 1 (June 24); 9 (August 30).
*Synedra acus Kütz.—Very common throughout most of the spring, summer, and fall.
*Synedra oxyrhynchus Kütz.—Seemingly very common at all periods.
*Synedra ulna (Nitzsch.) Ehrenb.—Very common to abundant in most plankton samples.

PROTOZOA

Mastigophora

Phytomastigophorea

Chrysomonadida:[1]
Dinobryon sertularia Ehrenb.—One occurrence in spring of 1955. 1 (June 24).
*Mallomonas pseudocoronata Prescott—Frequent in samples taken in early spring and late fall. 5 (September 14); 3 (October 21).

Dinoflagellida:[2]
Ceratium hirundinella (O.F.M.) Dujardin—Common during summer months.
Glenodinium armatum Levander—Fairly common in early spring (1956).
Glenodinium gymnodinium Penard—Frequent in spring and early summer samples. 0-10 (June 24-August 4).
*Glenodinium kulczynskii (Wolosz.) Schiller—Occasional occurrences in summer samples. 6 (August 30); 5 (September 22).
*Glenodinium pulvisculus (Ehrenb.) Stein.—Very common in spring and fall. 0-40 (August 15-October 21).

[1]Corresponds to algal Class Chrysophyceae, Division Chrysophyta.
[2]Corresponds to algal Class Dinophyceae, Division Pyrrhophyta.

*Glenodinium quadridens (Stein) Schiller—Very common to abundant in early and mid-summer. (This was the most common species of Glenodinium). 2-5 (July); 10-175 (August); 9-10 (September 12-14).

Phytomonadida:[1]

Carteria klebsii (Dang.) Dill—Occasional occurrences in mid-spring samples.

Chlamydomonas globosa Snow—Very common in early spring (1956).

Chlamydomonas snowii Printz—Frequent in early spring samples (1956).

Chlamydomonas spp.—Includes one or two species that are relatively common in spring and fall.

Coccomonas orbicularis Stein—Infrequent occurrences in early summer samples. 0-160 (August 2-29).

*Eudorina elegans Ehrenb.—Very common sporadically in spring and early summer. 3 (June 9); 3 (August 2).

Pandorina morum (Müll.) Bory—Very common sporadically as indicated, for example, by a sample taken in mid-July, 1952.

*Phacotus lenticularis (Ehrenb.) Stein—Very common in spring and early summer. 5 (September 22).

Euglenida:[2]

Astasia sp.—Common in early spring (1956).

Anisonema emarginatum Stokes—Common in early spring (1956).

*Euglena acus Ehrenb.—Fairly common in late summer (1955).

*Euglena cysts—0-16 (July 8-August 29).

*Euglena ehrenbergii Klebs—Very common during spring and summer months. 0-6 (June 24-October 21).

*Euglena gracilis Klebs—Very common during spring and summer months. 0-168 (July 8-October 21).

*Euglena intermedia Klebs—Common in fall (1955). 0-5 (September 14-October 21).

Euglena minuta Prescott—Fairly common in spring and fall.

*Euglena oxyuris Schmarda—Common to abundant during summer months (1955). 0-4 (June 9-October 21) (Counts include E. tripteris).

*Euglena tripteris Dujardin—Very common during summer months (1955).

*Lepocinclis acuta Prescott—Occasional occurrences in samples taken in the fall of 1955 and spring of 1956.

*Lepocinclis ovum (Ehrenb.) Lemmermann—Very common in spring and early summer. 0-60 (June 9-October 21).

*Phacus acuminatus Stokes—Common during summer months. 12-81 (August 15-30); 0-18 (September 12-October 21) (Counts include P. curvicauda).

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[1]Corresponds to algal Class Chlorophyceae (Order Volvocales), Division Chlorophyta.

[2]Corresponds to algal Division Euglenophyta.

*Phacus acuminatus var. drezepolskii Skvortzow–Common in summer plankton samples and in shad digestive tracts.

*Phacus chloroplastes Prescott–Infrequent in early spring samples, fairly common in fall. 5 (September 22).

*Phacus curvicauda Swirenko–Fairly common during 1955 summer.

*Phacus helikoides Pochmann–A single specimen found in shad gizzard.

*Phacus longicauda (Ehrenb.) Dujardin–Fairly common in early summer. 0-25 (June 24-August 20).

*Phacus orbicularis Huebner–Very infrequent in 1955 samples.

Phacus pseudoswirenkoi Prescott–Occasional occurrences in early spring samples (1956).

*Phacus pyrum (Ehrenb.) Stein–Common in early spring (1956). 27 (August 30); 5 (September 23); 9 (October 21).

*Phacus swirenkoi Skvortzow–Common in plankton samples and shad digestive tracts (1955).

*Phacus spp. 1 (June 10); 0-72 (August 2-September 23) (In some counts species were not all identified).

*Phacus tortus (Lemm.) Svortzow–Very infrequent occurrences in 1955 samples.

Scytomonas pusilla Stein–Common in early spring (1956).

*Trachelomonas granulosa Playfair–Fairly common during summer months.

*Trachelomonas volvocina Ehrenb.–Common during spring, summer, and fall months.

*Trachelomonas spp.–Includes several common but unidentified species. 0-8 (June 9-August 2); 5 (September 22); 3 (October 21) (Counts include above two species.

Zoomastigophorea

Rhizomastigida:

*Multicilia lacustris Lauterborn–Apparently rare. In one or two samples taken in the spring of 1955.

The Quotient Hypothesis as an aid in establishing the trophic status of North Twin Lake

In recent years, much attention has been given the prospect of designating the trophic nature of lakes on the basis of phytoplankton species composition. A large amount of limnological research has prompted the conclusion that each of the several phytoplankton taxa attains its best development species-wise under varying combinations of environmental conditions. It is well known for example that the Cyanophyta, the Chlorococcales of the Chlorophyta, the Euglenida, and the Centrales of the Bacillariophyceae possess what is known as a eutrophic tendency. On the other hand, the Desmidiaceae of the Chlorophyta and the Pennales of the Bacillariophyceae generally exhibit strong oligotrophic tendencies. On the basis of such information, quotients involving the numbers of species of certain phytoplankton taxa have been formulated so as to reflect the trophic nature of aquatic environments (e.g. Thunmark, 1945; Nygaard, 1949).

Since many of the assumptions relative to the trophic tendencies of certain of the phytoplankters involved in these quotients have been found to be invalid due to the wide ranges of conditions under which some of these organisms (eurybionts) can exist, the method has been subjected to some criticism (Rawson, 1956b). Nygaard (1955) himself questioned the validity of the method when he determined that his "compound quotient" failed to exhibit good agreement in the middle of the trophic range when compared with results of another method (photosynthetic activity) for ascertaining trophic types. The quotient methods have by no means been discarded, however, and it is believed that for most situations such criteria have a definite usefulness. They should continue to be improved upon as more information regarding trophic preferences of phytoplankton is acquired.

Since a considerable amount of information concerning the species composition of the North Twin Lake phytoplankton has been obtained, it was felt that the application of one of the aforementioned phytoplankton quotients might be helpful in ascertaining more precisely the trophic nature of the lake. Of the several quotients that have been devised, the compound quotient proposed by Nygaard (1949) was selected as probably being the most accurate for this purpose. The formula for this quotient is:

$$\text{Compound Quotient} = \frac{\text{Myxophyceae} + \text{Chlorococcales} + \text{Centrales} + \text{Euglenida}}{\text{Desmidiaceae}}$$

where each taxon is represented by the number of species it comprises in the particular body of water being studied. Applying the quotient to the North Twin Lake data we obtain:

$$\text{Compound Quotient} = \frac{35 + 72 + 8 + 26}{11} = \frac{141}{11} = 12.8$$

which indicates, according to Nygaard, that North Twin Lake is distinctly eutrophicated and may even be somewhat contaminated.

It is emphasized by Nygaard that this quotient should not ordinarily be used alone but should be regarded as supplementary to other limnological data. Hence the quotient obtained above helps to definitely substantiate the lake's trophic status which was previously determined on the basis of more general characteristics.

The estimated volumes (Table 2) indicate that diatoms constituted the bulk of the plankton (32.5 per cent). However, the diatoms were abundant only in the spring when _Stephanodiscus niagarae_ and _Melosira granulata_ comprised a major part of the plankton. Blue-green algae were second in total plankton bulk (30.9 per cent) and their peak was in midsummer. _Aphanocapsa delicatissima_ (Fig. 1) was by far the most important species in 1955. This form attained its best development toward the end of August. Although it was very abundant during this period, this blue-green alga never developed into bloom proportions.

Table 2. Summary of North Twin Lake plankton, 1955–composition by major taxa

Taxon	No. of species*	Per cent of total volume		
		Phytoplankton	Zooplankton	Plankton
Phytoplankton	236	100.0	-	84.3
Cyanophyta	35	36.6	-	30.9
Chlorophyta	93	18.6	-	15.7
Chrysophyta	62	38.6	-	32.5
Fungi	3	trace	-	trace
Mastigophora	43	6.2	-	5.2
Zooplankton	122	-	100.0	15.7
Protozoa	44	-	27.9	4.4
Rotatoria	49	-	54.9	8.6
Crustacea	20	-	16.4	2.6
Other	9	-	0.8	0.1
Total plankton	358	-	-	100.0
Tripton	-	-	-	308.2

Ratio of phytoplankton volume to zooplankton volume: 5.4:1.

*Includes all species encountered during the period 1951-1956.

Other blue-greens that contributed measurably to the phytoplankton but only for relatively short periods included Anabaena spiroides, Anabaenopsis elenkini, and Aphanizomenon flos-aquae. Microcystis aeruginosa, usually a trouble-maker in North Twin Lake, was noticeably reduced in abundance in 1955. The highest volume for this form was recorded on June 24.

It might be pointed out here that even though the blue-green algae comprised a major portion of the North Twin Lake plankton during the 1955 summer, objectionable forms such as Microcystis, Anabaena, Aphanizomenon, and Coelosphaerium were either consistently reduced or were abundant only for very short periods, never attaining bloom proportions. These high-floating conspicuous forms were replaced in the plankton by other less conspicuous and less bouyant forms such as the dominant Aphanocapsa delicatissima.

Green algae (Chlorophyta) were represented during the 1955 summer by a greater number of species than that possessed by any other taxon but constituted a relatively small portion of the bulk of the phytoplankton and total plankton volumes. Important components of the green algae from the volumetric standpoint were species of Oocystis (Fig. 1), Pediastrum, Scenedesmus, Coelastrum (Fig. 1), and Golenkinia. Highest development of green algae seemed to occur during October.

Flagellates contributed little to total plankton (5.2 per cent) volumes but were well represented in most samples. Volumetrically, the most important of these forms were *Euglena* spp., especially *E. tripteris* (Fig. 1) and *E. gracilis* (Fig. 1), *Phacus* spp., and *Glenodinium quadridens* (Fig. 1).

The Zooplankton

All zooplankton identifications were made by the author with the assistance of Dr. E. R. Becker, Iowa State College, who confirmed determinations of certain protozoan genera; Dr. W. T. Edmondson, University of Washington, who verified the identification of the rotatorian species, *Anuraeopsis fissa* Gosse; and Dr. M. J. Ulmer, Iowa State College, who assisted in identifying distorted specimens of the rotatorian species, *Asplanchna priodonta* Gosse.

The classification of the amoeboid and ciliate Protozoa is that followed by Hall (1953). Generic determinations of these forms were based upon the keys of Pennak (1953) and the keys and descriptions of Kudo (1954). Certain Sarcodina species were determined with the aid of keys given by Edmondson (1918). The very fine work of Kahl (1930-35) was helpful in identifying several species of the Ciliophora.

Rotatorian genera were determined with keys formulated by Pennak (1953). Specific determinations of Rotatoria necessitated the use of keys and/or descriptions given by many authors and widely scattered throughout the literature. The various works referred to in the present study and the genera they covered were: Ahlstrom (1940), *Brachionus*; Ahlstrom (1943), *Keratella*; Beauchamp (1932), *Ascomorpha*; Carlin (1939), *Colurella*; Carlin (1943), *Polyarthra*; Harring (1916), *Lepadella*; Harring and Myers (1926), *Lecane* and *Monostyla*; Hudson and Gosse (1886), *Macrochaetus* and *Philodina*; and Rylov (1935), all others.[1]

Cladocera, Copepoda, and miscellaneous invertebrates other than Crustacea were identified with keys given by Pennak (1953). The keys and descriptions of Hoff (1942) were used to identify the few Ostracoda encountered.

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[1] Just prior to presstime, the following important work appeared which is destined to be a boon to all planktologists, limnologists, invertebrate zoologists, and biologists in general; "Rotatoria. Die Rädertiere Mitteleuropas" by M. Voigt. 1956-57. Gebrüder Borntraeger, Berlin-Nikolassee. I Textband mit 27 Textabbildungen, 508 S. u. II Tafelband mit 115 Tafeln. This treatise consolidates most if not all major works on Rotatoria and includes keys to and descriptions of practically all known species of this highly cosmopolitan group of animals.

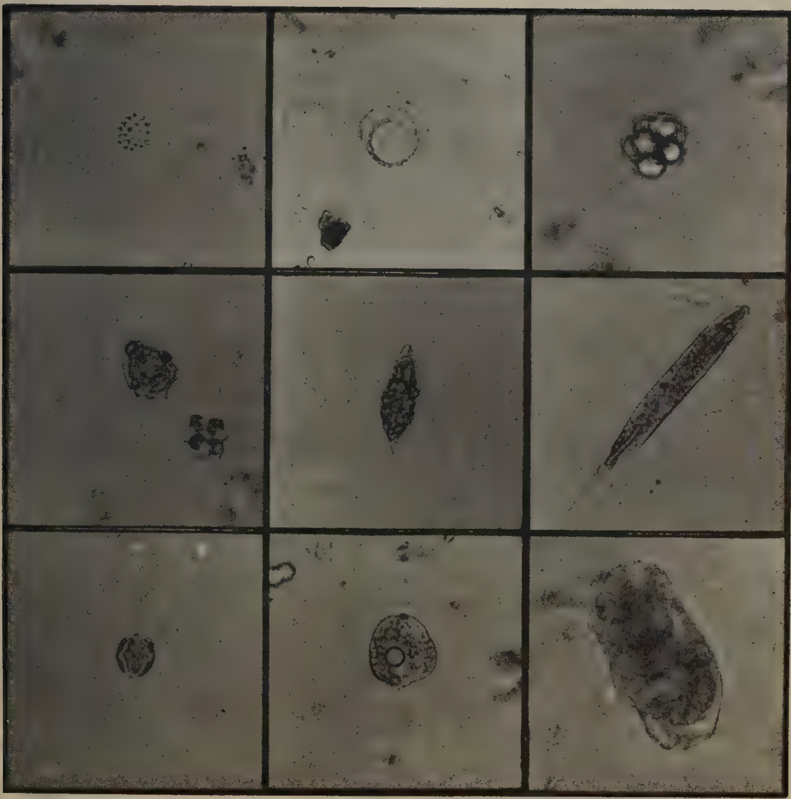

Fig. 1. Some common North Twin Lake plankters, 1955.

Top row, left to right:

<u>Aphanocapsa</u> <u>delicatissima</u> West and West (Cyanophyta)
<u>Anabaenopsis</u> <u>elenkini</u> V. Miller (Cyanophyta)
<u>Oocystis</u> <u>parva</u> West and West (Chlorophyta)

Middle row, left to right:

<u>Glenodinium</u> <u>quadridens</u> (Stein) Schiller (Protozoa:Mastigophora)
(A small colony of <u>Coelastrum</u> <u>microporum</u> Naegali (Chlorophyta) lies just below and to the right of the <u>Glenodinium</u> <u>specimen</u>.)
<u>Euglena</u> <u>gracilis</u> Klebs (Protozoa:Mastigophora)
<u>Euglena</u> <u>tripteris</u> Dujardin (Protozoa:Mastigophora)

Bottom row, left to right:

<u>Phacus</u> <u>chloroplastes</u> Prescott (Protozoa:Mastigophora)
<u>Phacus</u> <u>acuminatus</u> Stokes (Protozoa:Mastigophora)
<u>Anuraeopsis</u> <u>fissa</u> Gosse (Rotatoria)

(Photos by the author, 430 X enlarged three-fold)

PROTOZOA

Sarcodina

Actinopodea

Helioflagellida:

Dimorpha mutans Gruber–Fairly common in early spring (1956).

Heliozoida:

Acanthocystis aculeata Hertwig and Lesser–Common in early spring (1956).

Actinophrys sol Ehrenb.–Common during early summer months (1954, 1955).

*Actinosphaerium eichorni Ehrenb.–Common, especially in spring and early summer. .02 (July 8).

*Heterophrys glabrescens Penard–Common during spring and early summer (1955). 0-162 (August 2-October 21).

Rhaphidiophrys sp.–Occasional occurrences in summer samples.

Rhizopodea

Amoebida:

Amoeba gorgonia Penard–Found in samples taken in early spring (1956).

Amoeba spp.–Various unidentified forms in early spring samples (1956).

Testacida:

Arcella vulgaris Ehrenb.–Occasional occurrences in summer and fall samples. 5 (September 9).

Centropyxis aculeata Stein–Uncommon to common in spring and early summer.

Clypeolina marginata Penard–Frequent occurrences in spring of 1955. 3 (June 9).

Cochliopodium bilimbosum (Auerbach)–Very common in early spring (1956).

*Difflugia corona Wallich–Fairly common in late spring (1955).

*Difflugia lobostoma L.–Very common, occurring in most samples. 0-36 (June 9-October 6) (Counts include other Difflugia spp.).

*Difflugia pyriformis Perty–Common, occurring in most samples.

*Difflugia urceolata Carter–Occasional occurrences in plankton samples and in shad digestive tracts (1955).

*Difflugia spp.–Includes one or two common but seemingly variable forms.

*Euglypha alveolata Dujardin–In shad gizzard (1955).

*Euglypha sp.–Very infrequent in spring and fall samples (1955). .03 (September 12).

*Pseudodifflugia gracilis Penard–Fairly common in most samples.

*Pseudodifflugia sp.—Common, occurring in most samples along with P. gracilis. 0-28 (June 10-October 6) (Counts include P. gracilis).

*Trinema enchelys (Ehrenb.)—Not detected in plankton samples; found only in shad digestive tract.

Ciliophora

Euciliatia

Holotrichida:

Cinetochilum margaritaceum Perty—Common in samples taken in early spring (1956).

Coleps hirtus (Müller)—Common in early spring (1956).

Cyclidium sp.—Very common, especially during the 1955 spring and early summer. 0-37 (June 9-October 21).

Didinium nasutum (Müller)—Common in samples taken in late summer, 1954; occasional in 1955 samples. 2 (August 2).

Holophrya sp.—Uncommon in samples taken in spring of 1955.

Lacrymaria sp.—Occasional occurrences in 1954 summer samples.

Mycterothrix erlangeri Lauterborn—Uncommon. Encountered in spring samples (1955). .01 (June 24).

Paramecium sp.—Uncommon during summer months (1954).

Pseudoprorodon sp.—In samples taken in the spring of 1955.

Spirotrichida:

*Codonella cratera (Leidy)—Common to abundant, seemingly reaching peak production in spring and early summer. 0-15 (June 9-October 6).

Epalxis sp.—One occurrence in late summer (1955). .01 (June 24).

Halteria grandinella (Müller)—Common in early spring (1956).

Stentor sp.—Very infrequent occurrences in 1955 samples. 4 (June 9).

*Strobilidium sp.—Infrequent occurrences throughout the 1955 summer. 0-4 (June 24-August 4).

*Strombidium sp.—Infrequent occurrences throughout the 1955 summer.

Peritrichida:

Cothurnia annulifera Stokes—Several occurrences in samples taken in July, 1952.

Epistylis sp.—Colonies fairly common in samples taken in spring, 1955. .01-.13 (June 24).

*Hastatella radians Erlanger—Very common in spring and early summer, 1955. 10-24 (August 2-4); 9 (August 30).

*Vorticella spp.—Very common in late summer and fall (1955). 10 (August 30); 0-1 (September 22-October 21).

ROTATORIA

Bdelloidea:

*Philodina roseola Ehrenb.–Tychoplankter. Common in summer and fall (1955). 0-.09 (August 17-October 6).

Rotaria sp.–Tychoplankter. A single occurrence - in sample taken in April, 1956.

Flosculariacea:

*Conochiloides natans (Seligo)–Common in spring and early summer (1952, 1955). .4 (June 24); .008 (August 16); 0-.36 (August 30-September 23).

Conochilus unicornis Rousselet–Uncommon; several colonies encountered in early summer (1955). .007 (June 24).

*Filinia longiseta (Ehrenb.)–Very common in most samples; one of the six commonest rotifers. .16-2.08 (June 24-September 6); .01-.3 (September 23-October 21) (Counts include F. terminalis).

*Filinia terminalis (Plate)–Common.

*Pedalia mira (Hudson)–Common throughout much of the summer (1955). 0-.33 (June 24-September 12).

Pompholyx camplanata Gosse–Seemingly most abundant during the 1952 summer.

Ploima:

*Albertia sp.[1] –Identification questionable; taken in a single plankton sample (1955); common in digestive tracts of young shad (1955).

*Anuraeopsis fissa Gosse–Very common during mid-summer, especially in 1955. 0-2.7 (August 2-October 21).

*Ascomorpha ecaudis Perty–Uncommon, only a few individuals being observed in 1955. 0-.05 (July 8-September 14).

*Asplanchna priodonta Gosse–Common only in late spring and early summer. 0-.24 (June 9-August 2).

*Brachionus angularis Gosse–Very common, occasionally abundant in midsummer. .01-1.37 (June 9-October 6).

*Brachionus calyciflorus Pallas–Very common, attaining peak abundance in early spring. 0-.42 (August 17-September 14).

*Brachionus caudatus Barrois and Daday (f. vulgatus)–Common throughout the summer months. 0-.83 (June 9-September 23).

*Brachionus quadridentata Hermann–Uncommon, sporadic in occurrence. .008 (August 16).

*Brachionus urceolaris Müller–Occasional specimens observed during 1955 summer. 0-.02 (August 4-30).

Cephalodella sp.–Infrequent occurrences in 1955 samples. .008 (September 24).

*Colurella obtusa (Gosse)–Uncommon during the 1955 summer. .02-.05 (August 16-17).

*Dicranophorus sp.–Tychoplankter; infrequent occurrences in 1955 and 1956 samples. .01 (September 12).

[1]This form is in fairly close agreement with description of Albertia given by Harring and Myers (1928).

Euchlanis dilatata Ehrenb.–Uncommon; several specimens observed in 1954 and 1955. .004 (June 24); .026 (August 2).

Gastropus stylifer Imhof–Fairly common in 1952 samples.

*Keratella cochlearis (Gosse)–Very common; peak abundance is attained in spring and early summer. .09-5.3 (June-July); .008 (August 4) (Counts include next form).

*Keratella cochlearis var. hispida (Lauterborn)–Common in spring and early summer, occurring along with K. cochlearis.

*Keratella quadrata (Müller)–Common only in late spring and early summer. .01-.05 (June 9-10).

*Lecane luna (Müller)–Occasional specimens observed in 1955. .01 (August 15).

Lepadella patella (Müller)–Uncommon during the 1955 summer. .01 (August 30).

Macrochaetus collinsii (Gosse)–Apparently rare; several specimens observed in a single sample (1955). .02 (August 16).

Monostyla closterocerca Schmarda–Uncommon during the 1955 summer. .008 (August 2); 0-.37 (August 29-September 12).

*Monostyla hamata Stokes–One specimen observed in shad digestive tract.

*Monostyla obtusa Murray–Encountered only in shad digestive tracts.

*Monostyla pygmaea Daday–A single specimen observed in shad gizzard (1955).

*Monostyla pyriformis Daday–Fairly common in 1955 samples and in shad digestive tracts. Harring and Myers (1926) report M. pyriformis from sphagnum bogs only but the North Twin Lake specimens fit their description of this form quite accurately. .01-.1 (June 24-July 8); 0-.045 (August 16-September 23).

Mytilina ventralis (Ehrenb.)–Uncommon; several specimens observed in 1955. .007 (June 9).

Notholca acuminata (Ehrenb.)–Abundant but for a short period only in early spring.

Notommatidae (Unidentified)–Several specimens observed in 1955. .007 (June 24); .025 (August 16).

*Polyarthra major (Burckhardt)–Common sporadically. .02-3.7 (June 24-October 21) (Counts include next species).

*Polyarthra vulgaris Carlin–Very common throughout the spring, summer, and fall months.

Rousseletia sp.–Only one specimen observed (1955).

Synchaeta oblonga Ehrenb.–Uncommon; most specimens were observed in 1952 and 1954 samples. .008-.02 (July 8-9).

*Trichocerca cylindrica (Imhof)–Very common in spring and early summer. .1-5.- (June 9-October 21) (Counts include all Trichocerca spp.).

*Trichocerca lata (Jennings)–Fairly common in spring and early summer.

*Trichocerca longiseta (Schrank)–Common during summer months.

*Trichocerca rousseleti (Voigt) –Seemingly very common during midsummer period.

*Trichocerca similis (Wierzejski)–Fairly common during summer months.

*Trichocerca stylata (Gosse)–Very common during summer and early fall (1955).

*Trichocerca spp.–Includes several small species of infrequent occurrence in 1955 samples.

Eggs of rotifers were found in plankton from June 9–October 21. Numbers ran as high as 42 per milliliter.

ARTHROPODA

Crustacea

Branchiopoda

Cladocera:

*Bosmina longirostris (O.F.M.)–Very common in late spring and early summer; one of the commonest of the Cladocera. .02-.4 (June-July); 0-.01 (August 2-30).

*Ceriodaphnia pulchella Sars–Common in late spring (1955).

*Ceriodaphnia quadrangula (O.F.M.)–Common in late spring, early summer, and fall. 0-.03 (June 24-August 30).

*Chydorus faviformis Birge–A single specimen noted in shad gizzard (1954).

*Chydorus sphaericus (O.F.M.)–Very common during summers of 1951, 1952, and 1953; fairly common in 1954 and conspicuously absent in 1955; in shad gizzards (1954).

*Daphnia longispina (O.F.M.)–Very common, especially in late spring and early summer; one of the principal foods of very young game and pan fishes. 0-.16 (June 10-July 9).

*Daphnia pulex (deGeer)–Common, occurring with D. longispina in spring.

*Diaphanosoma brachyurum (Lievin)–Common in 1952 net plankton samples.

Leptodora kindti (Focke)–Uncommon in plankton samples; occasional specimens found in fish stomachs.

*Leydigia quadrangularis (Leydig)–Not taken in plankton samples; occasional specimens found in fish stomachs.

Macrothrix laticornis (Jurine)–Fairly common in late spring and early summer.

*Moina micrura Kurz–Especially common during the 1955 summer when it constituted one of the principal foods of young game fishes. .01 (June 9); .01-.03 (August 30).

Polyphemus pediculus (L.)–Occasional specimens found in fish stomachs.

Scapholeberis mucronata (O.F.M.)–Not taken in plankton samples. Several specimens found in stomachs of small fish in 1954 and 1955.

Ostracoda

*Cypria obesa Sharpe–Tychoplankter (occasional); not taken in plankton samples; occasionally present in food of small fish.

**Cypridopsis vidua* (O.F.M.)–Not taken in plankton samples; several occurrences in food of small fishes.

Copepoda

Eucopepoda:

**Cyclops bicuspidatus* Claus–Common to abundant; including its larval stages, this form is the most common of the planktonic Crustacea. (This was the only species of *Cyclops* detected in the North Twin Lake samples.) .003-.079 (June-July); 0-.015 (August 2-29).

**Diaptomus oregonensis* Lillj.–Common to abundant only for rather brief periods in late spring and early summer. .016-.053 (June); 0-.015 (August 2-20).

Orthocyclops modestus (Herrick)–Littoral form; occasional occurrence in 1955 samples.

Paracyclops fimbriatus (Fisher)–Tychoplankter; occasional occurrence in 1955 samples.

Nauplii were observed on many occasions. .06-.22 (June-July); 0-1.15 (August 2-October 21).

Arachnoidea

Hydracarina:

**Limnochares* sp.–Adventitious plankter not taken in plankton samples but frequently found in fish stomachs.

*Unidentified larvae–Tychoplanktonic; occasional occurrences in 1955 samples. .008 (August 17).

Insecta

Collembola:

**Podura aquatica* L.–Tychoplanktonic; not taken in plankton samples but found in shad digestive tract (1955).

Diptera:

Ceratopogonidae (larvae)–Adventitious plankter of very infrequent occurrence in 1955 samples.

**Chaoborus punctipennis* Say (Larvae: early instar)–Very infrequent plankter. .008 (August 16).

*Tendipedidae (Unidentified larvae)–Adventitious plankters of very infrequent occurrence in 1954 and 1955 samples. .004 (June 24); .008 (August 16); .008 (September 16); .01 (October 6).

MISCELLANEOUS PLANKTON FORMS

ANNELIDA

Oligochaeta:

Aeolosoma variegatum Vejd.–Tychoplanktonic; one or two occurrences in 1954 samples.

NEMATODA

Unidentified–Frequent occurrences in samples taken during the 1955 summer. .004 (June 24; 0-.03 (August 2-September 16).

BRYOZOA

*Plumatella sp. (Statoblasts)–Occasional occurrences in 1954 and 1955 samples. 0-.03 (August 29-September 12).

In general, zooplankton constituted a relatively small portion (15.7 per cent) of the total North Twin Lake plankton volume during the 1955 study period (Table 2). Such an occurrence is about what would have been expected for this period, i.e., that the producers (phytoplankton) be volumetrically in excess of the consumers (zooplankton) which they support. Such results are rarely obtained in studies involving net plankton only, where the bulk of the consumers usually exceeds that of the producers. This problem has been the concern of limnologists for many years (e.g., Rawson, 1956a) and it is generally agreed that the apparent fallacy is due to the inability of the net to retain the usually abundant nannoplankton. Refined plankton sampling techniques such as the centrifuge or sedimentation methods offer practical means for avoiding such pitfalls.

Amoeboid and ciliate Protozoa were important components of the North Twin Lake zooplankton during most of the study period but like the remainder of the zooplankton, comprised little of the total plankton volume. Of the Sarcodina, the actinopod, Heterophrys glabrescens, and rhizopods, Difflugia spp. and Pseudodifflugia gracilis, were the important forms. Difflugia spp. were consistently the most frequently occurring of these forms.

Relatively speaking, ciliates did not attain the same degree of importance on a volumetric basis as did the Sarcodina although Codonella cratera occasionally approached such a position. Other ciliates that reached measurable proportions in the plankton at various periods were Hastatella radians in early August, Cyclidium sp. throughout the late summer, and Vorticella sp. in late October.

Except for the month of June, Rotatoria consistently made up the bulk of the zooplankton encountered in the samples. Considered collectively, they comprised 54.9 per cent of the zooplankton volume and 8.6 per cent of the total plankton volume (Table 2). Species of five genera more or less dominated the rotifer populations at practically all times. These genera were Anuraeopsis, Brachionus, Filinia, Polyarthra, and Trichocerca. Considered from the standpoint of their bulk and the frequency with which they occurred in samples during the study period, the principal species were Anuraeopsis fissa, Brachionus angularis, B. caudatus, Filinia longiseta, Polyarthra vulgaris, Trichocerca longiseta, T. rousseleti, and T. stylata. Several of these rotifers were described by Carlin (1943) as typical summer forms. Other species attained significant proportions for relatively short periods at various times during the season. For example, Asplanchna priodonta, Keratella cochlearis,

Trichocerca cylindrica and T. lata seemed to be the important forms during the month of June. Brachionus calyciflorus, Conochiloides natans, and Notholca acuminata are very common at even earlier periods as was revealed by the analysis of several samples obtained in March and April of 1956.

Cladocera and Eucopepoda did not contribute measurably to the plankton except during the early stages of the study. At this time, Bosmina longirostris, Daphnia longispina, D. pulex, Cyclops bicuspidatus and Diaptomus oregonensis were the important forms. Their frequent occurrence in the digestive tracts of fish collected during this period furthur substantiated the relative magnitude of their abundance.

It is believed, however, that the plankton Crustacea were not as adequately sampled as might have been desirable. Although their relative abundance is usually low compared to that of most other plankters, they nevertheless constitute upon occasion an important segment of the total plankton volume and should be measured as accurately as possible. The acquisition of larger water samples would have undoubtedly reduced the sampling error and, consequently, the errors associated with estimating the volume of these bulkier but less numerous organisms. Better volumetric estimates of these forms would quite likely have lowered the phytoplankton-zooplankton (p:z) ratio somewhat although it is felt that the reduction would not have been appreciable.

Fairly well documented is the fact that in many waters planktonic crustacean production declines markedly during the hot summer months. Such was the case at North Twin Lake during the 1955 summer even though it is acknowledged that the sampling procedure followed may not have been as efficient in capturing these large zooplankters as would have been desirable. Analyses of fish digestive tract contents (including those of gizzard shad) suggested that fairly good populations of Cladocera and Eucopepoda existed even when plankton sample analyses failed to reveal their presence. However, the fact that the fish examined may have selected or actually sought out these forms more or less precludes making statements concerning abundance of these plankters based upon their incidence in the fishes' food.

It seems worth mentioning here that the analyses of the several samples obtained in March and April, 1956, employing exactly the same method used in 1955 also indicated that Cyclops bicuspidatus was the dominant zooplankter during the early 1956 spring. Furthermore, it is significant to note that computed p:z ratios for these samples were slightly in favor of the zooplankton. Hence, on the basis of these findings, it might be concluded that most samples obtained and analyzed by the methods described earlier are fairly representative even though they may not appear to be at first glance.

SUMMARY

In summarizing, it might be pointed out further that the series of samples taken from North Twin Lake employing the centrifuge method of concentration have lucidly exhibited from both numerical and volumetric standpoints the typical annual phyto-zooplankton production cycles,

namely, high zooplankton and comparatively low phytoplankton development in early spring followed by a sharp decline in zooplankton production and high phytoplankton development during the summer.

The tripton or planktonic abioseston was usually present in fairly large amounts, its bulk averaging about three times that of the planktonic bioseston.

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THE SOLUBILITY OF WATER VAPOR IN FUSED ALKALI NITRATE MIXTURES AND IN LITHIUM PERCHLORATE[1]

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It has long been recognized that certain salts dissolve unusual amounts of water. For example Dantuma (1) found that it was difficult to keep molten $LiNO_3$ dry in his studies on viscosity of fused salts. However, very little quantitative work has been done on the solubility of water vapor in fused ionic media. Galinker and Korobkov (2) studied the interaction of water and the fused alkali hydroxides, and studies have been made on the hydrolysis of the fused alkali halides (3). More recently, Laitinen (4) has discussed the problem of obtaining dry LiCl, and Keenan (5) has studied the freezing point of ammonium nitrate containing water, showing that water dissolves without ionization or association.

The present work was undertaken to provide quantitative data on the solubility of water vapor in some fused salts as a function of pressure, temperature and salt composition.

Experimental

The apparatus consisted of a vacuum line having four outlets; attached to these were a Cenco Hyvac pump in series with a mercury diffusion pump, a cell containing fused salt, a manometer and a reservoir containing water vapor. The whole apparatus, excluding the pump and the fused salt, was enclosed and heated to 42°C so that water vapor pressures up to 6 cm of Hg could be used conveniently; the cell with the fused salt was contained in a constant temperature bath of fused $NaNO_3$-KNO_3-$LiNO_3$ eutectic maintained to 0.5°C. The cell was attached to the vacuum line in such a manner that it could be mechanically rocked back and forth, pivoting about a ground glass joint. In operation, 10 g of the salt to be studied was placed in the cell along with a number of glass beads to aid stirring. The cell was then attached to the line and evacuated. The salt was brought to the melting point and up to the operating temperature while the pump was running; the pumping was continued for several hours to ensure complete dryness of the salt, as indicated by the equilibrium pressure after turning a stopcock to isolate the pump.

After closing the stopcock to the fused salt cell, water vapor was allowed to enter the system to the desired pressure; then the stopcock to the salt was opened and the pressure measured at time intervals of several minutes until no further drop occurred, a period of two to three hours. The volumes of the line and of the cell exclusive of fused salt

[1]Contribution No. 552. Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.

had been previously measured, using argon pressure. Thus the amount of dissolved water was easily calculated from initial and final pressures.

A liquid air trap was placed between the pump and the vacuum line. At no time were either nitric acid or oxides of nitrogen found in the trap.

The manometer was so designed that the volume of the system remained constant regardless of the pressure. Readings of the height differences in the mercury column were made with a cathetometer accurate to 0.05 mm.

It was found that the solubility of water vapor in $NaNO_3$-KNO_3 mixtures containing no Li^+ was too small to be detected over the temperature range of this work. Upon the addition of $LiNO_3$, the solubility became measurable. In the case of the perchlorates, only pure $LiClO_4$ was included in the data because pure $KClO_4$ and $NaClO_4$ and mixtures of these salts with $LiClO_4$ decompose, with the evolution of O_2, too rapidly for data on water vapor pressure changes to be obtained.

It was found that at all compositions of salt and at all temperatures, the solubility of water vapor is a linear function of its pressure. The Henry's law constants are listed in Table 1 in the units of moles of water vapor per millimeter Hg pressure per mole of Li^+ salt.

Table 1

Composition $LiNO_3$-$NaNO_3$-KNO_3 (mole %)	T°C	$K \frac{\text{moles } H_2O}{(\text{mm Hg x moles } Li^+)} \times 10^6$
30 - 23 - 47	145	23.8
30 - 23 - 47	170	13.0
30 - 23 - 47	175	8.8
30 - 23 - 47	205	3.2
12.5 - 46.4 - 41.1	240	1.02
24.8 - 39.9 - 35.3	240	2.07
30.0 - 37.1 - 32.9	240	2.50
46.7 - 28.2 - 25.1	240	10.0
67.0 - 17.5 - 15.5	240	27.4
86.9 - 6.9 - 6.2	240	49.7
pure $LiClO_4$	240	54.9
pure $LiClO_4$	260	28.5
pure $LiClO_4$	290	20.2

The ΔH of solution of water in the nitrate mixture (30 - 23 - 47, $LiNO_3$, $NaNO_3$, KNO_3 in mole per cent) is -13 + 4 Kcal. In $LiClO_4$, ΔH of solution is -9 $\pm$ 3.5 Kcal.

The solubility per mole of Li^+ varies approximately as the square of the Li^+ concentration. It thus appears that, on the average, approximately two Li^+ ions must cooperate to dissolve one water molecule.

One of the more interesting aspects of this work is the strikingly greater solubility of water vapor in the melts containing Li^+ ion. This can be qualitatively explained on the basis of ion-dipole interaction of this ion with the negative end of the water dipole; the term which most affects the energy of interaction is proportional to r^{-4}, where r is the distance of closest approach of the center of positive charge to the negative dipole of the water molecule. Evidently, Na^+ ion and larger cations and the anions are too large for the energy of the ion dipole interaction to be comparable to that of the coulombic interaction between the ions of the salt.

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TRANSAMINATION IN PROPIONIBACTERIUM JENSENII[1]

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INTRODUCTION

Transamination reactions have been reported in a large number of plants, animals, and microorganisms (13) and play an important role in amino acid synthesis (6). Recent re-examination of the amino acid nutritional requirements of the propionic acid bacteria in these laboratories indicates that, contrary to earlier opinion, these organisms are capable of synthesizing a large number of amino acids. In studying the possible mechanisms of these syntheses a transaminating system has been found which has not been reported previously. Some transamination reactions catalyzed by crude cell-free extracts of Propionibacterium jensenii have been studied and are reported here.

MATERIALS AND METHODS

Propionibacterium jensenii ATCC 4867 was used throughout. Stock cultures were maintained by monthly transfer in yeast extract-lactate agar stabs.

Heavy cell crops were obtained by growing starter cultures at 30° in yeast extract-lactate broth and transferring these cultures in the late logarithmic phase (5 ml inoculum per 500 ml broth) to a medium containing 1 per cent yeast extract (Difco) and 1 per cent sodium lactate solution (Fisher, about 60 per cent pure, density = 1.31 g/ml). Cultures were incubated at 30° without shaking and harvested after 44-54 hours when the cells were in the maximum stationary phase of growth. Cells were harvested on the Sharples supercentrifuge and stored as a paste at -20° without washing until used.

Crude cell-free extracts were prepared by washing the cells four times in cold distilled water, suspending in distilled water to a density of 0.5 g wet weight/ml, and treating 30 min. in the Raytheon 9 kc sonic oscillator. Cellular debris was removed by centrifugation 5 min. at 24,500 X g at 0°. Extracts prepared in this way contained 2.5-3.5 mg protein/ml (15) using sodium caseinate (Difco) as standard.

Transaminase activity was determined at 37°. Exact composition of the reaction mixtures is given below. Although addition of pyridoxal phosphate to crude sonic extracts did not appear to stimulate transamination, it was included routinely in all reaction mixtures. Reactions were stopped by inactivating the enzyme by addition of trichloracetic acid or by heating 5 min. at 100°. Control flasks were included in each

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experiment from which amino donor, amino acceptor and enzyme were each omitted. Zero time controls showed no evidence of nonenzymatic transamination. Formation of the appropriate amino acid in the complete system and its absence in the controls, as well as results of balance studies involving the amino acids in quantitative experiments, were taken as evidence of transamination.

Reaction mixtures were analyzed by means of paper chromatography using aqueous phenol as solvent. Quantitative determinations of amino acids were made by measurement of spot areas under carefully standardized conditions or by elution of the spots and measurement of the ninhydrin color at 560 mμ (2). Results obtained by both methods were in good agreement.

RESULTS AND DISCUSSION

The following amino acids were tested qualitatively for their ability to donate the amino group to α-ketoglutaric acid: DL-α-aminobutyric acid, DL-alanine, DL-arginine, DL-aspartic acid, γ-aminobutyric acid, glycine, L-histidine, L-hydroxyproline, L-isoleucine, DL-leucine, L-lysine, DL-methionine, DL-norleucine, DL-phenylalanine, L-proline, DL-serine, taurine, DL-threonine, DL-tryptophane, L-tyrosine, and DL-valine. In addition L-asparagine, L-glutamine, and the inorganic ammonium ion were tested. Each flask contained 175 μM phosphate buffer, pH 7.4, 25 μM amino donor (where DL-amino acids were used concentrations were calculated on the basis of the L-isomer), 50 μM neutralized α-ketoglutaric acid, 20 μg pyridoxal phosphate and 0.5 ml crude sonic extract in a total volume of 2.60 ml. The reaction mixtures were incubated at 37° for 4 hours.

Only seven amino acids donated the amino group to α-ketoglutarate: DL-α-aminobutyric acid, DL-aspartic acid, γ-aminobutyric acid, L-isoleucine, DL-leucine, DL-norleucine, and DL-valine. These acids formed well-defined glutamic acid spots on paper chromatograms, whereas controls showed only the faintest traces of endogenous glutamic acid. Although yeast extract-grown cells of P. jensenii contain high concentrations of intracellular free amino acids and peptides (unpublished experiments), washing four or five times with distilled water extracted these effectively from the cells so that no interference with chromatographic analyses occurred. Of the seven donor amino acids aspartic acid was by far the most active. It was surprising that neither asparagine nor glutamine was a donor since experiments have shown that P. jensenii is able to grow well, though slowly, in chemically defined media containing glucose, vitamins, and minerals with these two amides as sole nitrogen source (unpublished data). Although the propionic acid bacteria have been reported capable of utilizing inorganic ammonia as a nitrogen source (16), all attempts in this laboratory to confirm this with P. jensenii have been unsuccessful. Ammonium ion as sole nitrogen source does not support growth of this organism, nor can the disappearance of inorganic ammonia be detected in the presence of organic nitrogen. No glutamate formation could be detected when ammonium chloride was tested with α-ketoglutarate in transamination experiments.

Although D-amino acids have been shown to be active in transamination reactions in bacteria (9, 13, 17), the activity of the seven positive amino acids appears to be limited to the L-isomers. Experiments in which the L-isomers were replaced by the D-isomers showed only insignificant traces of glutamic acid even after incubation periods of eight hours at 37°.

Glutamic acid was tested as an amino donor to two other biologically important α-keto compounds, oxalacetic and pyruvic acids. L-glutamic acid was incubated in the presence of neutralized oxalacetic or pyruvic acids, phosphate buffer, pH 7.8, pyridoxal phosphate and crude sonic extract at 37°. High concentrations of aspartic acid were detected after 30-60 minutes' incubation in the presence of oxalacetate, but no alanine formation from pyruvate was found even after eight hours' incubation. It is interesting that the latter reaction, one of the first transaminations to be described and one of the most common (5), is absent in this organism.

Crude sonic extracts formed nearly twice as much glutamate from aspartate and α-ketoglutarate as washed whole cells. Washed whole cells (0.5 g wet weight/ml) were suspended in distilled water and divided into two portions. One portion was treated in the Raytheon apparatus to prepare a crude sonic extract; the other portion was left untreated. Separate reaction mixtures were prepared containing 175 μM phosphate buffer, pH 7.4, 100 μM DL-aspartic acid, 50 μM neutralized α-ketoglutaric acid, 20 μg pyridoxal phosphate and 0.5 ml whole cell suspension or crude cell extract in a total volume of 2.35 ml, and incubated 6 hours at 37°. The reaction was stopped by heating with precautions to prevent loss by evaporation and the mixtures were analyzed for glutamic acid. In flasks containing whole cells 2.9 μM glutamate/ml were formed, whereas flasks containing the cell-free enzyme contained an average of 5.3 μM glutamate/ml. Whether this result was due to a permeability factor, which limits the availability of the substrate to the enzyme, or the disruption of other enzyme systems which compete for substrates or products, is not known. Since the reactions were stopped by heating, one would expect that glutamic acid formed would be extracted and not locked up within the cells.

Crude sonic extracts of _P. jensenii_ retained their activity for the reversible aspartate-glutamate reaction for periods as long as seven weeks when stored at -20°; however, repeated thawing and freezing caused considerable precipitation, presumably of denatured protein, with simultaneous loss of activity. Less precipitation occurred when crude extracts were stored at 4°, but activity was retained for shorter periods and fell off sharply after 6-7 days.

A number of workers have studied the pH dependence of transaminases from different sources. This dependence varies greatly according to the source of the enzyme and the reactions catalyzed. Lichstein and Cohen (11) found that the glutamate-oxalacetate transaminase of _Escherichia coli_ showed maximum activity at pH 8.5. Transaminases of _Neurospora crassa_ catalyzing the ornithine-, phenylalanine-, and isoleucine-α-ketoglutarate reactions were most active at pH 8, that for the aspartate-α-ketoglutarate reaction at pH 9, while the alanine-α-ketoglutarate enzyme was most active at pH 6 (8). _Streptococcus faecalis_ glutamate-

oxalacetate transaminase, on the other hand, was little affected by pH, especially in the cell-free condition (12). Saccharomyces fragilis showed little dependence on pH for the reversible glutamate-aspartate reaction, whereas formation of glutamate from leucine and α-ketoglutarate was most rapid near pH 8 (1). Table 1 shows the concentrations of glutamate formed by a single crude enzyme preparation of P. jensenii from aspartate and α-ketoglutarate in two different buffer systems over a range of pH. For this reaction activity appears to be greatest at a pH between 6 and 7 although there is clearly not the sharp dependence on pH such as that exhibited by the data of Bigger-Gehring for the leucine-α-ketoglutarate reaction (1) or of Lichstein and Cohen (11) for the glutamate-oxalacetate reaction.

The results of experiments on the rates of the reversible aspartate-glutamate transamination reaction catalyzed by crude sonic extracts are shown in Fig. 1. The formation of aspartate from glutamate and oxalacetate is greater, in agreement with the results of other workers who have studied this reaction with enzyme from other sources (4, 10, 14). The data of Fig. 1 indicate that under the experimental conditions employed the reaction appears to be approximately linear with time and uncomplicated by competing side reactions. Aspartic acid is formed at the rate of 3.2 μM/ml/hr, whereas glutamate is formed by the reverse reaction at the rate of about 1.2 μM/ml/hr. This is a rate which is only about one-fiftieth that found by Feldman and Gunsalus for glutamate formed by E. coli and Pseudomonas fluorescens under similar experimental conditions (7). It would be interesting to determine whether this marked difference in reaction rates is characteristic of other intermediary metabolic reactions in a slow-growing organism such as P. jensenii or whether it might indicate merely the difference between an organism accustomed to assimilating preformed organic compounds and one accustomed to vigorous synthetic activity. No comparative studies have been made of transamination reactions with P. jensenii cells grown in chemically defined media. In quantitative experiments with P. jensenii small amounts of amino acids were formed compared to other microorganisms under similar conditions.

The equilibrium constant for the reversible aspartate-glutamate transamination reaction has been estimated on the basis of amino acid balance experiments. Calculation of the equilibrium constant from ten separate experiments gave values which varied from 0.13 to 0.58 for glutamate formation at pH 7.4 and 37°. The fact that no compensation was made for the spontaneous decomposition of oxalacetate over the variable time periods of these different experiments and that only crude enzyme preparations were used may account for these variations. Corresponding values were obtained when the equilibrium was approached from the opposite direction. These are in fair agreement with the equilibrium constants reported by other workers using enzyme preparations from other sources under slightly different experimental conditions (1, 4, 10, 14).

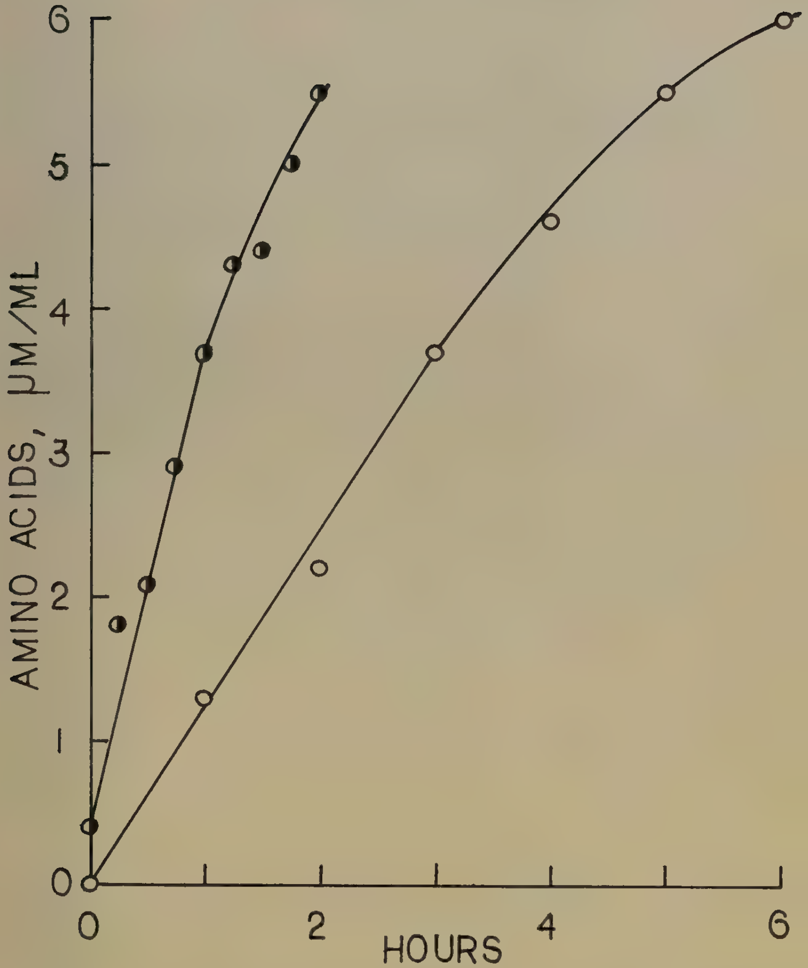

Fig. 1. Rate of the reversible aspartate-glutamate transamination reaction.

The reaction mixtures contained 200 μM phosphate buffer, pH 7.6, 25 μM L-glutamic acid or L-aspartic acid, 25 μM neutralized oxalacetic or α-ketoglutaric acids, 20 μg pyridoxal phosphate, and 0.5 ml crude sonic extract in a total volume of 2.60 ml. Incubated at 37°. Reaction stopped by addition of 0.2 ml 50% trichloracetic acid. ◑ = Aspartic acid. ○ = Glutamic acid.

Table 1. Effect of pH and buffer on the aspartate-α-ketoglutarate reaction.

The reaction mixtures contained 100 μM tris or phosphate buffer of the pH indicated, 37.6 μM neutralized L-aspartic acid, 15.0 μM neutralized α-ketoglutaric acid, 10 μg pyridoxal phosphate and 0.5 ml crude sonic extract in a total volume of 2.50 ml. Incubated 4 hrs at 37.5°. Reaction stopped by addition of 0.1 ml 50 per cent trichloracetic acid.

Buffer	pH	Glutamate formed (μM/ml)
Phosphate	6.0	3.0
	6.4	2.7
	6.8	3.1
	7.2	2.3
	7.6	2.1
	8.0	2.1
Tris	7.0	2.8
	7.5	2.6
	8.0	1.8
	8.5	1.4
	9.0	1.4

SUMMARY

Occurrence of enzymes catalyzing transamination reactions in crude sonic extracts of *Propionibacterium jensenii* is reported.

Of twenty-one amino acids, asparagine, glutamine, and ammonium ion tested with α-ketoglutarate as amino acceptor only seven amino acids showed evidence of glutamate formation: α-aminobutyric acid, aspartic acid, γ-aminobutyric acid, isoleucine, leucine, norleucine, and valine. Only the L-isomers were active.

Glutamic acid will serve as an amino donor to oxalacetate but not to pyruvate.

Crude enzyme preparations are stable for as long as seven weeks when stored at -20°, but only six days when stored at 4°.

The enzyme for the reversible aspartate-glutamate transamination shows only slightly greater activity at pH 6-7 when tested over the range pH 6-9 in phosphate and tris buffers. Determination of the equilibrium constant for glutamate formation gave values ranging from 0.13 to 0.58 at pH 7.4 and 37°.

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MEASUREMENT OF MAGNETIC FIELD GRADIENTS BY THE HALL EFFECT[1]

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ABSTRACT

A magnetic field gradient measuring device which uses the Hall effect in germanium has been constructed. The field sensitive element was a bar of germanium 1 mm by 1 mm by 12 mm with two sets of Hall leads each attached 2 mm from the center of the bar. With 100 cps current flowing in the long direction of the bar, the two Hall voltages were subtracted to give an output directly proportional to the magnetic field gradient. The instrument was tested in a calculable magnetic field produced by step pole pieces, and gradients from 5 gauss/inch to 500 gauss/inch in magnetic fields below 5000 gauss were measured. The instrument will also measure magnetic field strengths and relative gradients. The usefulness of the instrument is still uncertain because of errors caused by excessive field dependence of the gradient voltage.

INTRODUCTION

The testing and alignment of the large magnets used in high energy particle accelerators often require the measurement of magnetic field gradients. The quantities of interest are the magnetic field B, the gradient in magnetic field dB/dx, and the relative gradient $(dB/dx)/B$. The most promising methods (1, 2, 3) of field gradient measurement use vibrating or rotating coils. Motion of the coil mounting and matching of coils may be difficult problems, however, and the usefulness of such methods in time-varying magnetic fields is limited by the frequency of vibration (or rotation). The method described here uses the Hall effect to measure the magnetic field strengths at two adjacent points. The difference between these field strengths, which are measured simultaneously, is directly proportional to the gradient. The advantages of this method are that it uses a stationary probe, it gives an output directly proportional to the gradient, and, in principle, the device will follow rapid time variations in magnetic field strength. The purpose of this research was to determine the potential usefulness of this Hall method.

If a semiconductor in the form of a long, flat plate carries a current in the x-direction and a magnetic field is applied in the z-direction, then

[1]Contribution No. 551. Work was performed in the Ames Laboratory of the Atomic Energy Commission.

an electric field appears in the y-direction. This field produces the Hall voltage, $V = (RIB/t)10^{-8}$, where V is the Hall voltage in volts, R is the Hall coefficient in cm^3/coulomb, I is the current in amperes, B is the magnetic field in gauss, and t is the thickness in cm of the sample in the z-direction. The proportionality between V and B allows magnetic field strengths to be measured and instruments based upon this principle have been described by Pearson (4) and by Mason, Hewitt, and Wick (5). Since the current which can be sent through the Hall plate will be limited by the power which can be dissipated without undue heating, it is convenient to state V in terms of the power. The expression for the Hall voltage is then, $V = B(PW/Lt)^{1/2} (\mu R)^{1/2} 10^{-8}$, where W is the width of the plate in cm, L is the length of the plate in cm, P is the power input in watts, and μ is the mobility (R divided by the resistivity) in cm^2/volt-sec. A high sensitivity requires both a high mobility and a large Hall coefficient and, for this reason, germanium was considered the most suitable material. (If maximum power output rather than maximum voltage output were desired, however, InSb might be the preferable material (6).

DESCRIPTION OF INSTRUMENT

The field probe was a bar of germanium 1 mm by 1 mm by 12 mm with Hall leads each attached 2 mm from the center of the bar. One hundred cps alternating current flowed in the long direction of the bar so that in a magnetic field two 100 cps Hall voltages were obtained at two points of the field 4 mm apart. Each of these Hall voltages was fed through an isolation transformer and a phase-shifting network and then applied across a 100,000 ohm 10-turn Helipot. The voltages tapped off the two Helipots were connected in series and, by proper phase adjustment, the voltages were made to subtract. The difference voltage, which was proportional to the magnetic field gradient, was amplified and observed on a vacuum-tube voltmeter.

The germanium had, at room temperature, a resistivity of 12.4 ohm-cm and a Hall coefficient of $-5(10)^4$ cm^3/coulomb. The surface was etched and current leads were soldered to the ends. The Hall leads were attached by a microsoldering technique based on a method, described by W.H. Mitchell (7), which involved pressing a carefully tinned, five mil copper wire against the germanium surface and discharging a capacitor through the junction to melt the solder. After all the leads had been attached, Duco cement was poured over the germanium and wires in order to hold the leads permanently in place.

The circuit diagram is shown in Fig. 1. The current for the probe was supplied by a 100 cps oscillator and power amplifier having very good frequency stability. The output transformer T_3 had two secondary windings; the 1000 ohm winding supplied the probe current, and the low impedance winding furnished a "bucking signal." This bucking signal, which could be varied in amplitude and phase by the variable resistors R_7 to R_{10}, was fed to the narrow-band amplifier and used to cancel out constant background signals. The voltage across the 10-ohm resistor

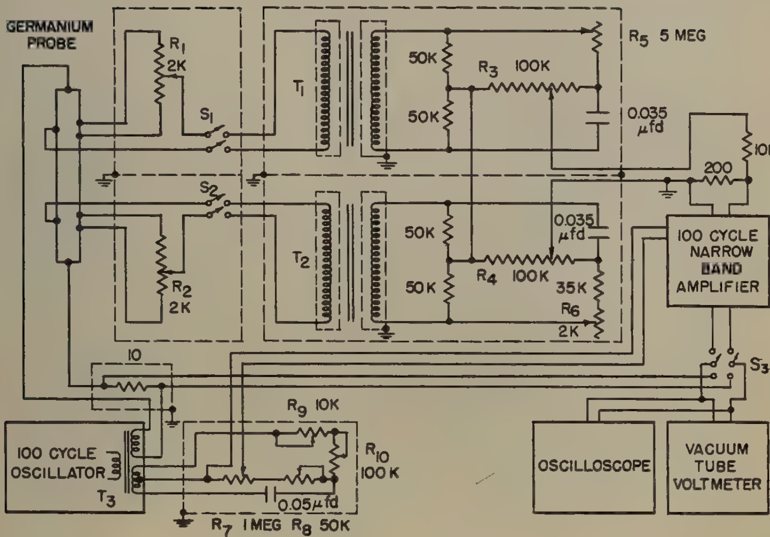

Fig. 1. Circuit diagram for measurement of magnetic field gradients by the Hall effect.

in series with the germanium probe could be connected to the vacuum-tube voltmeter in order to monitor the probe current. The two Hall voltages were sent through two similar channels. The resistors R_1 and R_2 were adjusted until there was no voltage at S_1 and S_2 in the absence of a magnetic field. (Opening either S_1 or S_2 made the instrument sensitive to magnetic field strength rather than field gradient.) The transformers T_1 and T_2 were necessary to isolate the two Hall probe sets. The transformers were General Radio Type 578B with electrostatically shielded windings. The electrostatic shielding was found to be essential for reducing background signals to a minimum. R_5 and R_6 were used as coarse and fine phase controls. This phase balance was necessary in order to have the two signals to be subtracted appear across R_3 and R_4 exactly in phase. Adjustment of R_3 or R_4 compensated for any difference in gain of the two channels or any differences in the Hall coefficients at the two points on the germanium bar. One of these resistors was always kept at maximum so that the over-all gain would be constant. The difference voltage, after passing through an impedance-matching network, was amplified by a narrow-band amplifier with a gain of about 10^6. The output of the amplifier could be measured on a vacuum-tube voltmeter or observed on an oscilloscope for polarity determination.

PERFORMANCE

To make a measurement the field probe was first held well away from the magnet and the probe balance potentiometers R_1 and R_2 were adjusted to give minimum output from each set of Hall leads. The small remaining difference voltage was balanced out with the bucking voltage. The probe was then placed between the poles of the magnet as near as possible to a position of zero gradient and the magnetic field set at the desired value. The amplitudes and phases of the two Hall signals were adjusted to cancel each other so that the output was again zero. Readings of the voltage output for different probe positions were then made as the probe was moved through the gap.

When the amplifier input was observed during the balancing of the probes with R_1 and R_2, it was found that at best balance, a badly distorted signal still remained. The distortion was caused, principally, by a large second harmonic produced by rectification at the Hall probe-germanium junctions. As long as measurements were made with the narrow-band amplifier, the effect caused no trouble, since only the 100-cycle component was passed by the amplifier. If it were necessary, however, to measure time-varying magnetic fields, a wide-band amplifier would be necessary and this rectification effect would then seriously limit the performance of the instrument.

In a uniform field the two Hall voltages should exactly cancel each other and there should be no difference voltage at any field strength. Measurements made in a uniform field, however, showed a very strong field-dependent difference voltage. This field dependence was caused by the fact that the individual Hall voltages were not exactly the same function of the magnetic field. In addition to linear terms which could easily be matched, the Hall voltages contained terms quadratic and cubic in the field strength which could not be balanced out. The quadratic term was predominant in the difference voltage and was a major source of error. It is known that the Hall coefficient of germanium is field dependent (5, 8) and that certain orientations of the current and magnetic field with respect to the crystallographic axes will minimize this field dependence. In the measurements to be described, a crystal with a highly unsymmetric orientation was used. A crystal cut with its surfaces parallel to the crystal axes was also tried, but the instrument was not significantly improved by this change.

To determine the performance of the instrument in regard to useful range, sensitivity, and accuracy, the gradient of a calculable magnetic field was measured and compared with the theoretical value. A calculable field was produced by special step pole pieces fitted to an electromagnet. The pole pieces consisted of two parallel plates of Armco iron 6 inches by 6 inches by 3/4 inch thick. Half of the surface of each plate was milled down to a prescribed depth to form a step along the center line. For a step in an infinite plane the magnetic field gradient in the median plane between the step pole faces, as a function of position along a line perpendicular to the step, is given in parametric form by the two equations,

$$(dB/dx)/B_o = (\pi/2h)(\alpha^2S^2-1)(1-S^2)/(\alpha^2-1), \tag{1}$$

and

$$x = (h/\pi)\left[\ln[(1+S)/|1-S|] - \alpha \ln[(\alpha S+1)/|\alpha S-1|]\,.\right] \tag{2}$$

The parameter $S = B/B_o$ is the ratio of the field strength B at the position x to the field strength B_o at $x = \infty$. The spacing of the pole faces for positive x is 2h and for negative x is $2\alpha h$; the height of the step is therefore $(\alpha-1)h$. Equations (1) and (2) were calculated with the aid of a Schwarz - Christoffel transformation (9, 10). The gradient at the edge of the pole faces requires a separate calculation. The complicated geometry at the edges of the pole faces makes an exact calculation very difficult. As a first approximation, however, it was assumed that the edge of the pole face could be considered as the corner of a very thick semi-infinite pole piece. The gradient produced by this geometry can also be solved with the aid of a Schwarz-Christoffel transformation (9, 11). The gradient in the median plane is given by

$$(dB/dx)/B_o = (\pi/2h)S^2(1-S^2), \tag{3}$$

and

$$x = (h/\pi)\left[\ln[(1+S)/|1-S|] - (2/S)\right] \tag{4}$$

The symbols have the same meanings as before except that x is now the distance from the edge of the pole piece measured along a line perpendicular to the edge. The quantity B_o was determined with the aid of Eq. (2) and a measurement of the field at the step.

The gradient calculated from these formulas is shown by the solid line in Fig. 2. The actual gradient should be slightly less then the theoretical gradient because of saturation of the iron at the cörners, which tends to smooth out the equipotential lines. At low field strengths the agreement between the experimental and theoretical gradients was reasonably good; but at higher field strengths (3430 gauss and 4220 gauss) an additional gradient appeared between the gradient caused by the edge and the gradient caused by the step. This additional gradient was produced by a saturation effect.

The poles of the magnet consisted of two cylinders each with a radius of two inches, faced with step-pole plates 6 inches by 6 inches. The area of each face outside the pole was therefore $36 - \pi 4 = 23.4$ inches^2. Since the square plates were 3/4 inch thick, all the flux leaving this area had to pass through a circular band of area $2\pi(2)$ (3/4 = 9.42 inches^2. The flux density in this band was thus approximately 2.5 times that at the surface. Hence, for a surface flux density of 4000 gauss, the flux density in the band was about 10,000 gauss and saturation effects were produced. This saturation caused the field to fall off before the edge was reached and hence gave rise to the observed extra gradient.

In terms of the output difference voltage ΔV, the gradient G is given by $G = K\,\Delta V/B_o$, where $K = t/(gRI\,\Delta x)$, and t is the thickness of the

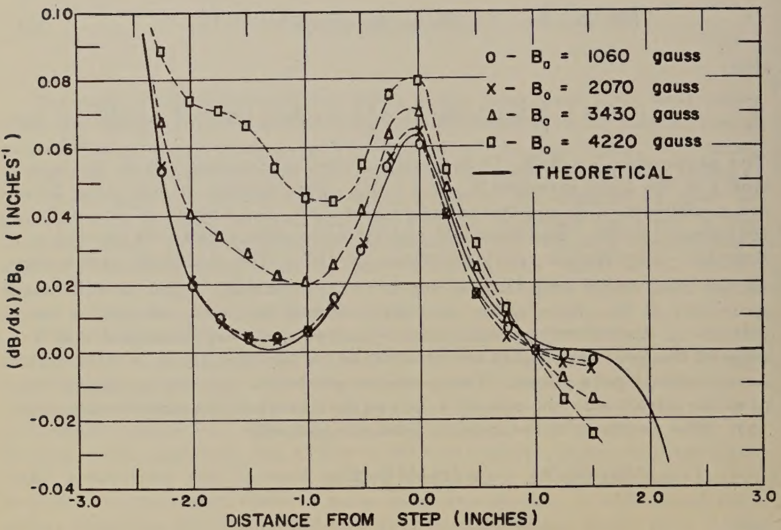

Fig. 2. Magnetic field gradients produced by step-pole pieces.

germanium bar, R is the Hall coefficient, I is the current through the bar, Δx is the probe spacing, and g is the gain of the system. The calibration constant K was determined by matching the experimental gradient with the calculated gradient at the peak gradient. Fig. 2 shows the gradient obtained with a step $(\alpha-1)h$ of 0.050 inches and a gap (2h) of 1.5 inches. The value of K used for all experimental points on this graph was 16.4 gauss/volt-inch and was determined by matching the experimental points for B_o = 1060 gauss with the peak of the calculated curve. The sensitivity of the instrument may be taken as $1/K = 0.061$ volts/(gauss/inch). The noise level of 0.2 volts corresponded to an absolute gradient of 3.3 gauss/inch.

The maximum gradient that could be measured was limited to about 500 gauss/inch owing to the dependence of the output voltage on field strength. The extra field dependent terms in the Hall effect formula, which led to this field dependence, also led to a nonlinearity in response. Hence the sensitivity was field dependent. The minimum gradient which could be measured was about 5 gauss/inch. This limit was set by the gain of the system and by the noise level. Perhaps the easiest way to increase the sensitivity would have been to use a thinner germanium bar in the probe. There is no lower limit to the field strengths at which the instrument will operate as long as the gradient is at least 5 gauss/inch. In fact, the lower the field strength, the better it will operate. No gradient measurements have been made in field strengths above 5000 gauss. Presumably all the difficulties encountered would have been worse at higher field strengths.

CONCLUSIONS

A magnetic field gradient measuring device which uses the Hall effect in germanium has been constructed. It has measured gradients from 5 gauss/inch to 500 gauss/inch with errors of less than 10 per cent in magnetic fields up to 5000 gauss. The major limitation of the instrument, at present, is the dependence of its output voltage on the strength of the magnetic field. Because of this field dependence, it has not been possible to adjust the zero at one field strength and use the instrument at a different field strength. The advantages of the instrument are its small, stationary probe and the fact that it is direct reading. It will follow gradients which exist over a distance less than one inch and the mounting can be simple and light. When only one channel is used, the intensity of the magnetic field can be measured; when both channels are used, the gradient of the magnetic field can be measured; and, when a simple adjustment of the amplitude dials is made, the relative gradient $(dB/dx)/B$ can be measured.

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